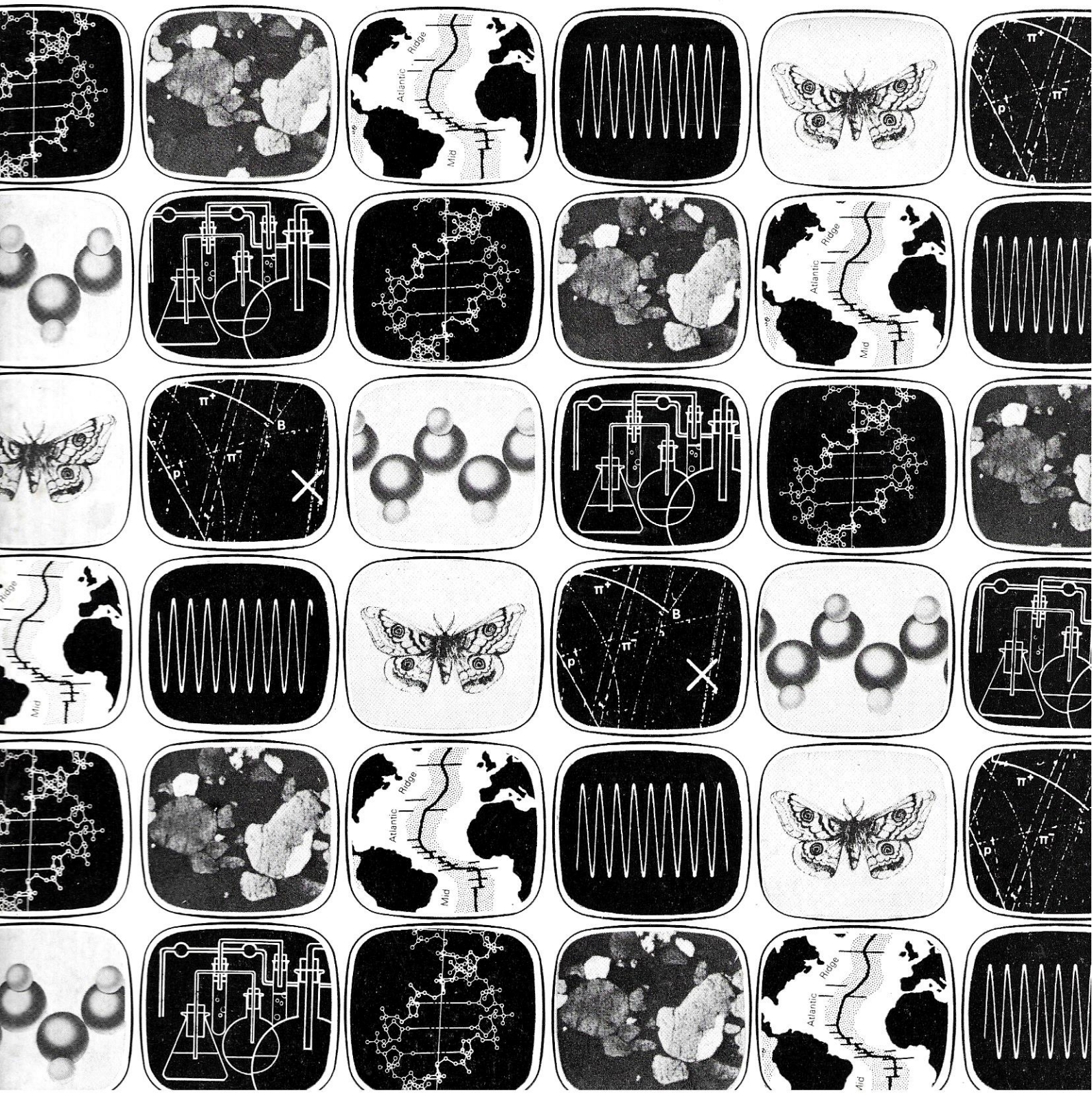
S100 BN

THE OPEN UNIVERSITY

Science : A Foundation Course

Broadcast Notes for Units 1–34



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2.1

INTRODUCTORY PROGRAMME

Pre-broadcast Notes

Subject
The Science Foundation Course

Speaker
Professor Michael Pentz

The Dean of the Faculty of Science, Professor Michael Pentz, will explain the structure of the Science Foundation Course and of the learning system that has been devised for it.

The Course itself is very different, in content and concept, from traditional science courses, and the learning system includes a unique combination of media and a number of techniques with which you may not be familiar.

The programme will make use of various illustrative devices, including some documentary film showing your predecessors at work, to help you make effective use of the materials the University is sending you.

This broadcast will be closely related to the *Introduction and Guide to the Science Foundation Course*, which you received in the first mailing, and with the Introductory Radio Programme. So you should read the *Introduction and Guide* again before you watch this programme.

Post-broadcast Notes

The *Introduction and Guide to the Science Foundation Course* should serve as 'post-broadcast notes' for this programme. You are strongly advised to consult the *Introduction and Guide* from time to time during the year, particularly Sections 4 and 5. You may well find that some things that seemed strange or a bit unreal when you first read them will have acquired more meaning and will be much more useful to you when you have actually come to grips with the problems of studying the Course, and have had some experience of using the system.

TELEVISION UNIT 1

Pre-broadcast Notes

Subject
Introduction to the Science Foundation Course

Speaker
Professor Michael Pentz

In this programme, Professor Michael Pentz (Dean of the Faculty of Science) will go over some of the main steps of Galileo's inclined plane experiment, using the same equipment as you have – a rubber ball, a stopwatch and an ordinary table.

As you may have noticed if you have already tried out this experiment, it may seem simple but there is a lot more to it than meets the eye.

You should, if possible, do the experiment before you view the television programme, as this will make it more interesting and more useful.

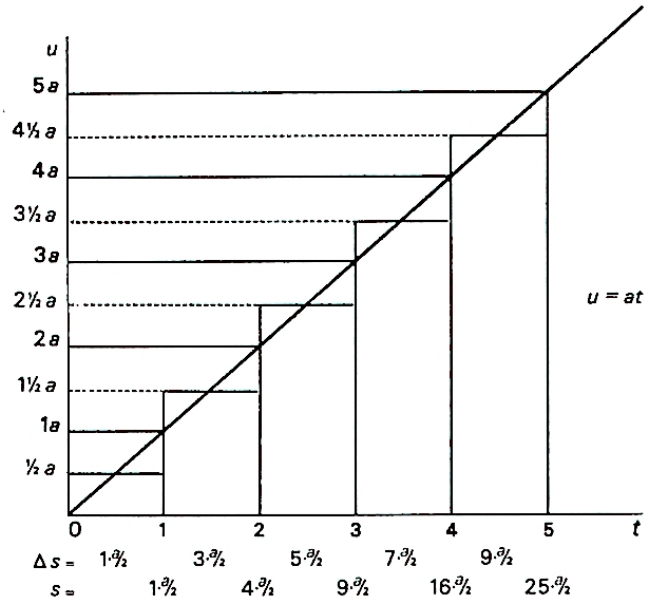
Since Galileo's experiment was one of the first scientific experiments – though it seems to have been done in a palace rather than a laboratory – Professor Pentz will discuss the question 'what *is* a laboratory' and compare the situation of the modern research scientist with that of Galileo.

Post-broadcast Notes

Part 1 From $u = at$ to $s = \frac{1}{2} at^2$

Galileo's basic hypothesis was that a body falling freely did so with constant acceleration. In other words, the velocity u increases in proportion to the elapsed time t, assuming that the body starts falling from rest.

We can illustrate this hypothesis with a velocity–time graph (a is the acceleration):



It is easy to see that the *average velocity* during the first second is $\frac{1}{2}a$, and so the distance travelled in that second, labelled Δs in the figure, is $\frac{1}{2}a \times 1 = \frac{1}{2}a$ metre, if u is in metre per second and t in second.

Similarly, the average velocity in the second interval of a second is $1\frac{1}{2}a$, or $3.a/2$ in the third interval, $5.a/2$ in the fourth, $7.a/2$, and so on.

The corresponding distances travelled in the successive intervals are shown in the figure.

So the *total* distances travelled can be found by simply adding up the distances travelled in the successive intervals.

As you can see, $s = \frac{a}{2}t^2$.

If you are familiar with elementary calculus, you will of course have obtained this result by simply integrating u with respect to t.

The point of this transformation, which was emphasized in the broadcast, is that Galileo's hypothesis in the form $s = \frac{1}{2}at^2$ could be checked experimentally with the techniques at his disposal, whereas in the form $u = at$ it could not.

Part 2 The cylinder race

In the television programme, Professor Pentz first raced two hollow steel cylinders against each other.

Cylinder A had an outer diameter of 10 cm and an inner diameter of 9 cm. Cylinder B had an outer diameter of 10 cm and an inner diameter of 1 cm.

Both cylinders were 20 cm long.

If you take the density of steel to be about 8×10^3 kg m^{-3}, you can calculate that the mass of Cylinder A was about 2.4 kg and the mass of Cylinder B about 12.5 kg.

Cylinder C had the same dimensions as Cylinder B, but it was made of *wood*.

If you take the density of wood to be about a tenth of that of steel, that makes the mass of Cylinder C about 1.2 kg.

As you will have seen, when A is raced down an inclined plane against B, B wins. B is, of course, the heavier of the two.

But when C is raced against A, C wins, though C is lighter than A.

If you consult Appendix 2 of the Main Text of this Unit (it is a '*Black*-page

appendix'), you will find that the time of descent of a hollow cylinder will be proportional to $\sqrt{(1 + \alpha)}$, where $\alpha = I/mR^2$.
I is the moment of inertia of the cylinder, m is its mass and R is its *outer* radius.

The larger the moment of inertia of the cylinder *relative to its own mass*, i.e. the larger I/m, the longer will be the time of descent.

The thin-walled cylinder has relatively more of its own mass near its outer radius than the thick-walled cylinder has. So the moment of inertia of the thin-walled cylinder, relative to its mass, is greater than the moment of inertia of the thick-walled cylinder, relative to *its* mass.

That is why the thin-walled cylinder always loses the race.

At the end of the third cylinder race, Professor Pentz said 'A dead heat.'

What do you think about that? How 'dead' does a heat have to be before everyone can be expected to agree that it really is 'dead'? How close to a dead heat had that third race to be to establish the essential point about rotational kinetic energy?

We suggest that you reflect on these questions. They are relevant to some quite fundamental points about science and scientific methods. We shall be commenting on this in one of the later Radio programmes.

TELEVISION UNIT 2

Pre-broadcast Notes

Subject
Observation and measurement
Speakers
Professor M. J. Pentz
Professor F. R. Stannard

This programme is mainly about the measurement of short time intervals. Having demonstrated the structure and mode of operation of a cathode-ray oscilloscope, we use the instrument in an experiment in which you will yourself participate. The purpose of the experiment is to measure the half-life of a small particle called the *muon*. This particle decays exponentially in a rather similar fashion to a radioactive nucleus, with a half-life of only about one-millionth of a second. With it we can kill two birds with one stone – we can combine the measurement of a short time interval with a study of exponential decay.

What are muons?

The earth's atmosphere is being continually bombarded by high-energy nuclear particles arriving from outer space. They collide with the nuclei and electrons of the atoms of the air. These fast moving particles, together with those arising from the collisions, are called *cosmic rays*. At sea level we are being continually irradiated by the debris from these collisions. Normally we are unaware of this because the particles are so tiny; it is necessary to have special instruments to detect them such as, for example, the cloud chamber you will see demonstrated at the beginning of the programme.

Most of the particles at sea level are electrons, but some are of a type called muons.* Muons have a mass about one-ninth the mass of the lightest atom – hydrogen. They can be either positively or negatively charged. We are interested only in those that are positively charged.

Muons are unstable and after about one-millionth of a second they break up. Because electric charge must be conserved a muon's positive charge has to be passed on to one of its decay fragments. The charge is in fact carried off by a positively charged electron. (Note, this is no ordinary electron such as is found in an atom. Although it has the same mass and *quantity* of charge, the *sign* of the charge is opposite.)

Although one-millionth of a second is a very short time interval, muons generally travel long distances before decaying. This is because they move so

* *A more detailed description of how muons are produced is deferred until Unit 32.*

quickly (close to the velocity of light, *viz.* 3×10^8 ms^{-1}). The chance of a muon decaying as it passes through a room is less than one in a thousand. So if we are to observe muons decaying we must somehow catch them. This is quite easy. Although they have considerable ability to penetrate objects (most of those aimed at your house have no difficulty in passing through the roof or walls), they do nevertheless slow down as they pass through material and the denser the material the more they slow down. In our experiment we use a block of lead. Most muons pass through it but some stop in it. Those that stop just stay put until they decay. On decaying the positively charged electron is ejected. It too slows down in passing through the lead. Some electrons stop in the lead and some emerge from it.

How do we know when a muon has gone into a block of lead and not come out again?

Moving electrons can be made to produce a flash of light on the screen of a cathode-ray oscilloscope or TV set. This happens as they pass into the fluorescent coating painted on the inside of the tube face. A similar kind of principle can be used to detect any charged particle. The charged particle, acting through its electric field, gives energy to the electrons in the atoms lying along its path, and in so doing alters their arrangement within the atoms. Some of these electrons subsequently revert to their original arrangement, giving off the excess energy in the form of light. Materials that emit light when a charged particle passes through them are called *scintillators*. Thus, in order to determine whether we have caught a muon, we place a scintillator above and below the block of lead. If both scintillators give a flash it corresponds to a particle passing straight through, as in Figure 1.

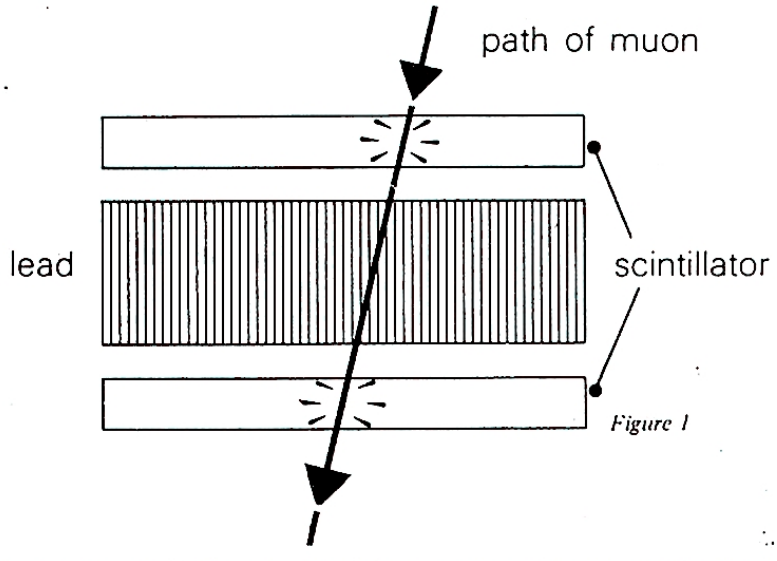


Figure 1

If only the top one flashes, we possibly have stopped a muon in the lead, as in Figure 2.

Why did we say 'possibly'? What else could have happened?

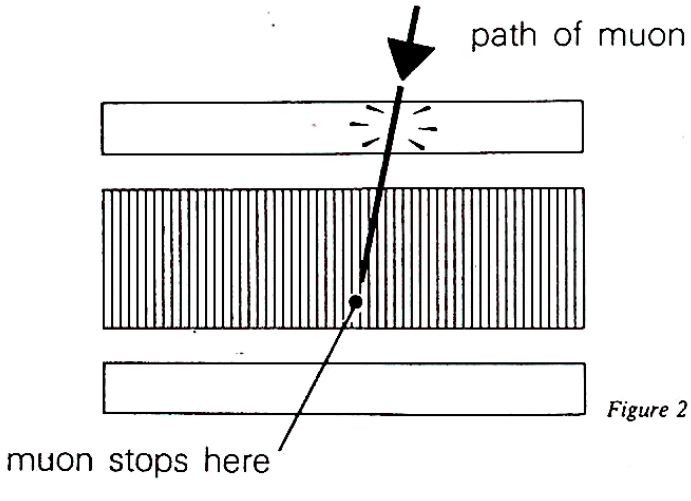


Figure 2

However, a flash in only the upper scintillator could be an indication of something quite different – see Figure 3.

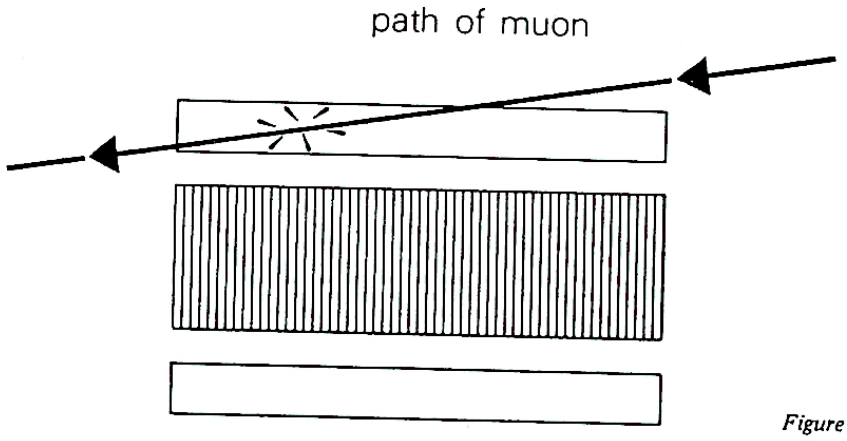


Figure 3

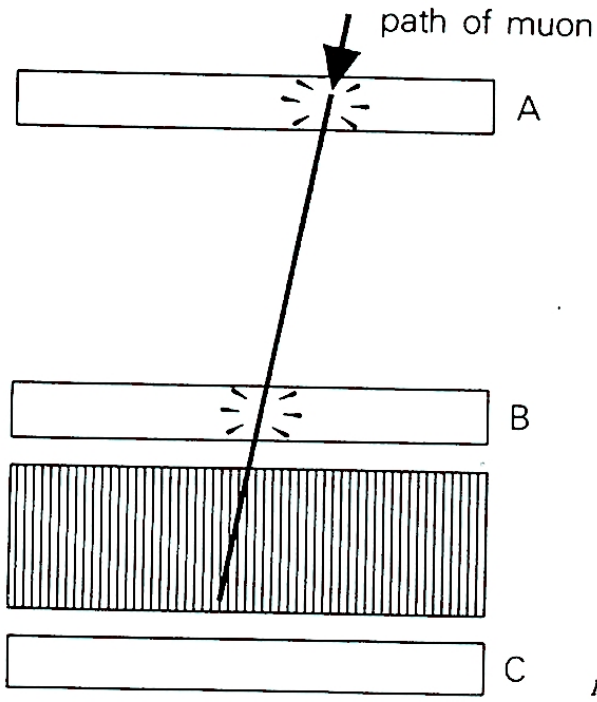


Figure 4

We can check that the particle is moving in a direction so as to strike the lead block by introducing a third scintillator, as in Figure 4. Now a count in A and B but not in C is a good sign that we have stopped a particle in the lead. We have advisedly said 'a particle' and not a muon because there are also a great many electrons flying about. Perhaps it was one of these and not a muon that passed through A and B. We can reduce the chance of this by inserting some lead between A and B, as in Figure 5. Unlike muons, electrons have little ability to penetrate materials so that they would be stopped in the first layer of lead between A and B. By requiring a flash in both A and B and not in C we know that a *penetrating* particle (i.e. a muon) has passed through A and B and been stopped in the second layer of lead.

But why you may ask does the muon stop in the second layer of lead and not in the first? Well, certainly some muons *will* stop in the first layer. However, muons arrive with various energies, so there will be some with enough energy to pass through one layer but not a second – it is these we will use in our investigation.

Knowing the time of arrival of the muon (by noting the time at which the almost simultaneous counts in A and B occurred), we now wish to detect the decay of the muon.

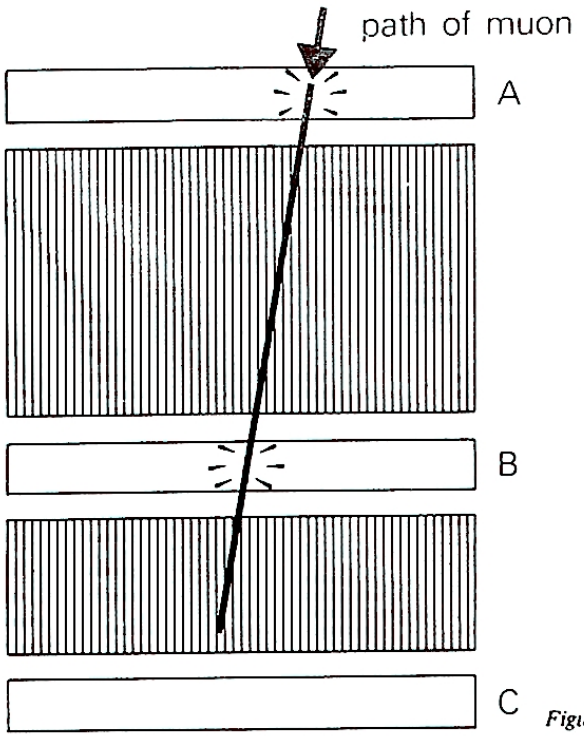


Figure 5

How do you suggest this is done with the set-up of Figure 5?

We said earlier that muon decays gave rise to positively charged electrons. Some of these shoot out of the lead and into scintillator B or C giving a flash. Thus the decay of the muon will be signalled by a single count in either B or C.

To summarize then:

We first require (I) a count in A and in B but not in C, then (II) a count in B or C but not in A.

The time between (I) and (II) is a measure of how long the muon lived while in the lead.

If the separation between A and B is, say, 0.3 m and the muon travels with a speed approaching that of light, *viz*. 3×10^8 ms^{-1}, then the time between the flashes in A and B is the distance travelled divided by the velocity, i.e.

$$\frac{0.3}{3 \times 10^8} = 10^{-9}\,s.$$

This you see is only one-thousandth of the time expected between (I) and (II). So, as we said a little earlier, to all intents and purposes the flashes in A and B can be taken as simultaneous and the only time interval of significance is that between (I) and (II).

How do we measure this time interval?

Each slab of scintillator is attached to a *photomultiplier tube*. At this stage you need to know nothing about this instrument other than its function which is to emit a pulse of electrical current on receipt of a flash of light. The piece of transparent scintillator together with its photomultiplier tube is called a *scintillation counter*.

The electrical pulses from each of the scintillation counters are passed to a panel of electronics (Fig. 6). This investigates the time intervals between the pulses and decides when situation (I) (i.e. A and B and not C) or (II) (B or C only) has occurred. On recognizing that situation (I) has occurred the panel initiates an electrical pulse to the cathode-ray oscilloscope, and this triggers the time-base. When it recognizes that situation (II) has occurred it sends a second electrical signal, this time to the YY′ plates.

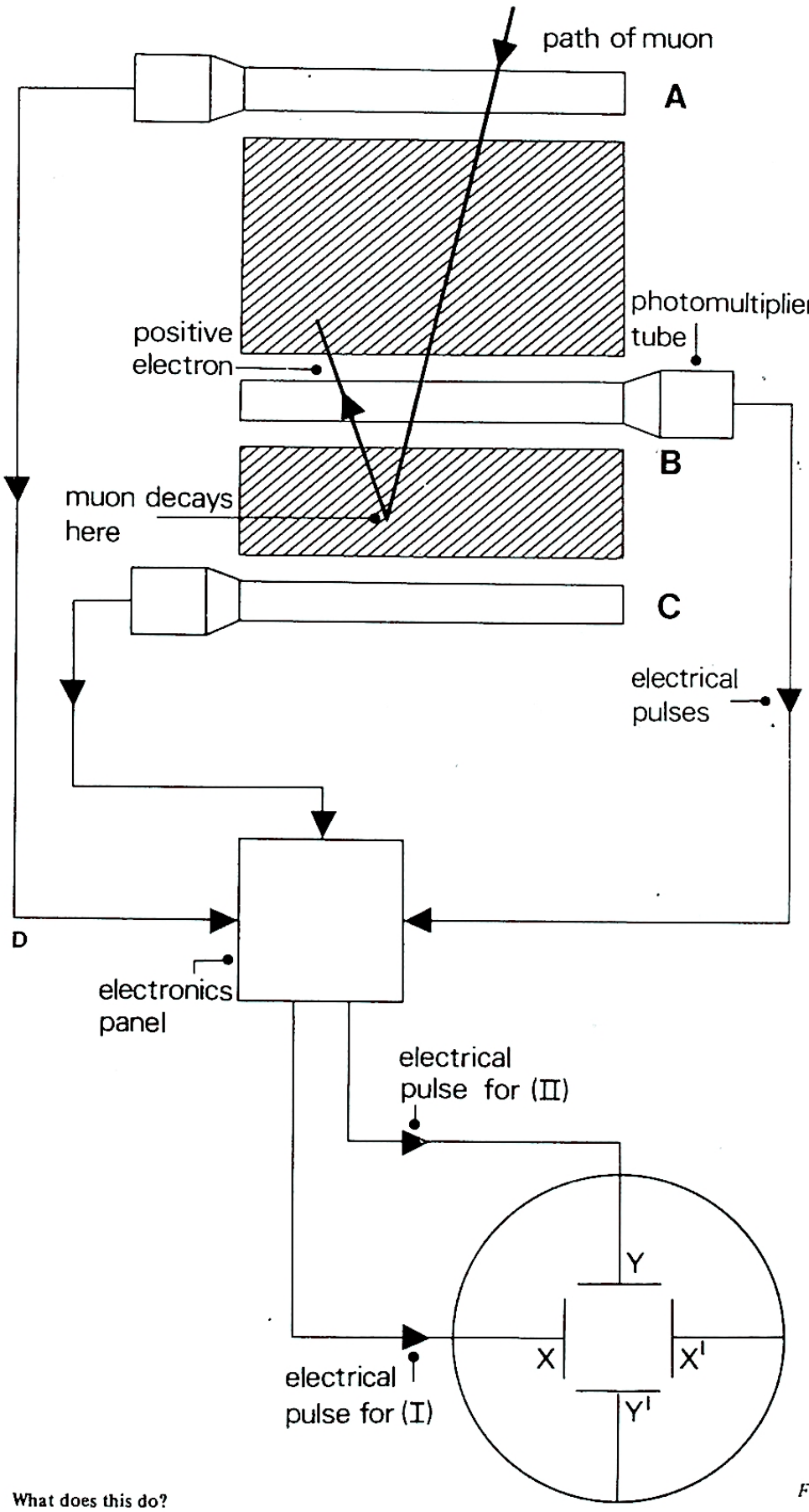


Figure 6

What does this do?

This causes the spot of light on the oscilloscope's screen to move vertically. Thus the distance from the start of the time-base to the point where the vertical blip occurs is a measure of the life-time of that particular particle. Before viewing the programme, be sure you have read Section 2.5.5 of the Main Text, in which the cathode-ray oscilloscope is described, and also consult the Home Experiment Notes for experiment No. 4.

Post-broadcast Notes

Do not worry unduly if you did not understand the principle of the cloud chamber. It was demonstrated simply to give direct and convincing evidence that we are at all times being bombarded by cosmic radiation.

Further description of the way in which a cathode-ray oscilloscope works will be given in the TV programme of Unit 4, after you have learnt a little more in that Unit about fields.

The data from the muon experiment have been supplied to you under the heading of Home Experiments for Unit 2, experiment 4. They consist of photographs of the oscilloscope screen taken with the experimental arrangement of Figure 6. Two time-base traces are shown per photograph. (This is simply an economy measure). You should now turn to the instructions for this experiment.

TELEVISION UNIT 3

Pre-broadcast Notes

The programme will be in two distinct parts:

Part 1 Momentum conservation

In the first part Dr Walton will demonstrate the principle of conservation of momentum. We advise you to read Sections 3.6.1 and 3.6.2 of the Main Text before viewing this programme.

Subjects
1 Momentum conservation
2 Speed of light
Speakers
Dr A. J. Walton
Professor F. R. Stannard

Part 2 Speed of light

In the second part, Dr* Stannard will show you a method of measuring the speed of light, using equipment in the Royal Institution, London. You will see how the experiment is performed, but you will not be told the outcome – that is for you to work out for yourself. The experiment is described in the *Post-broadcast Notes*. You might find it helpful to look at these notes *before* the broadcast.

We advise you to read Sections 3.2.2 and 3.2.3 of the Main Text before viewing the programme.

Dr Stannard will also show an animated film illustrating one of the consequences of the fact that the velocity of light is the same to all observers in uniform relative motion. The film shows that, what are simultaneous events to one observer need not appear to be simultaneous to another observer if the two observers are moving relative to each other.

Post-broadcast Notes

1 Summary of the programme

Part 1

Professor Pentz introduced the first part of the programme by showing how the idea of momentum conservation could be used to make an *indirect* measurement of the speed of an airgun pellet. He suggested that you might calculate the speed of the pellet yourself, using the data given below.

Dr Walton then used the airtrack to demonstrate collisions between gliders of equal and unequal mass, measuring their speeds by means of a pair of 'light gates' and a cathode-ray oscilloscope.

**Now Professor.*

The data obtained from one set of measurements are summarized below, and you are asked to verify that momentum was conserved in that collision. Professor Pentz then briefly indicated that an airtable could be used to study two-dimensional collisions; the principle of conservation of momentum would still apply, but now the directions as well as the speeds of the colliding objects would have to be taken into account.

Part 2

Dr Stannard first showed a simplified model of the apparatus to be used for measuring the speed of light. Then he showed the measurement being made with the apparatus itself.

The speed of light is measured directly by timing the pulses of light as they traverse two different distances. The pulses are generated by a spark, and travel, after successive reflections, to a photomultiplier tube, where they are detected and displayed on a cathode-ray oscilloscope. A computer is used to average the pulse profiles.

Further details of the experimental layout, and the data printed out by the computer are given below.

Dr Stannard introduced the animated film by reminding you that there is a remarkable thing about the speed of light - whenever you measure it you will always get the same answer. It does not matter what the motion of the source of light is, or what the motion of the observer is, you always get the same result. This gives rise to some peculiar consequences, particularly if you have two observers moving relative to each other and each of them insists that the speed of light is the same in all directions as far as *he* is concerned.

2 Data from the airgun experiment

We weighed ten pellets and found that their mass varied between 0.91 gm and 0.93 gm. The average value was 0.92 gm.

The mass of the glider (including the tube on top of it, in which we caught the pellet) was 494 gm.

We measured the speed of the glider by timing it over a distance of 1m. We observed the following times (each one for a separate firing of the airgun): 4.2, 4.4, 4.8, 4.4, 4.6, 4.2, 4.8, 5.0, 4.8, 5.0 seconds.

This, as you can verify for yourself, gives an average time of 4.6 seconds.

Now use the principle of conservation of momentum to work out the speed of the pellet.

Does this seem a plausible result to you? (If you have ever fired an airgun at a target, you might think of the delay you would expect between the moment of firing and the moment of arrival of the pellet at the target.)

You will find the speed worked out on page 13 of these notes.

What do you think would have been the main sources of (a) systematic error (b) random error in this measurement?

You will find a comment on this question on page 13 of these notes.

3 Data from the momentum conservation experiment

The following table records the velocities of the gliders before and after impact. Given the masses of the gliders, check whether momentum is conserved in the collision.

VELOCITIES in ms^{-1}	Larger glider mass = 0.4 kg	Smaller glider mass = 0.2 kg
Before the collision	0.48	0
After the collision	0.16	0.62

(These velocities were calculated from the times it took the 0.1 m flags to pass the timers. The times we measured from the oscilloscope were: 0.21 s, 0.16 s and 0.63 s.)

Is momentum conserved?

Bear in mind that draughts in the studio introduced errors in the timings, from which the velocities were deduced, of about 10 per cent.

You will find the calculation opposite.

4 Speed of light measurement: experimental layout and data

The layout is shown in the diagram (Fig. 1).

The pulses of light from the spark source S can be made to traverse either the distance d_1 (shown in black) or the distance d_2 (shown in grey), by adjusting the mirrors at A and D and using the additional mirrors B and C for the longer path.

It is not necessary to know the actual values of the distances d_1 and d_2 or of the times taken for the light pulses to travel the two different distances; only the *differences* in distance and time are needed.

The speed of light can then be estimated from the formula

$$c = \frac{d_2 - d_1}{t_2 - t_1}$$

where t_2 and t_1 are the times taken for the light to travel the distances d_2 and d_1 respectively.

As you can see from the diagram,

$$d_1 = SA + AD + DP$$
$$d_2 = SA + AB + BC + CD + DP$$

So $d_2 - d_1 = AB + BC + CD - AD$

These lengths were measured and found to be:
AB = 2.32 m, BC = 2.25 m, CD = 2.21 m, AD = 2.30 m.

Calculate $d_2 - d_1$

Reproduced in Table 1 (p. 13) is the printed output from the computer, giving the averaged intensity profiles of the light pulses traversing distance d_1 (column A) and d_2 (column B).

We have used the numbers given in this graph to plot the height against the time on a graph (p. 14).

Draw a curve through each set of points.

These curves reproduce the profiles you saw displayed on the cathode-ray tube screen *of the computer* in the TV programme.

Estimate the position of the dip in each curve. Measure the time interval between the two dips. This is $(t_2 - t_1)$. Hence calculate the speed of light.

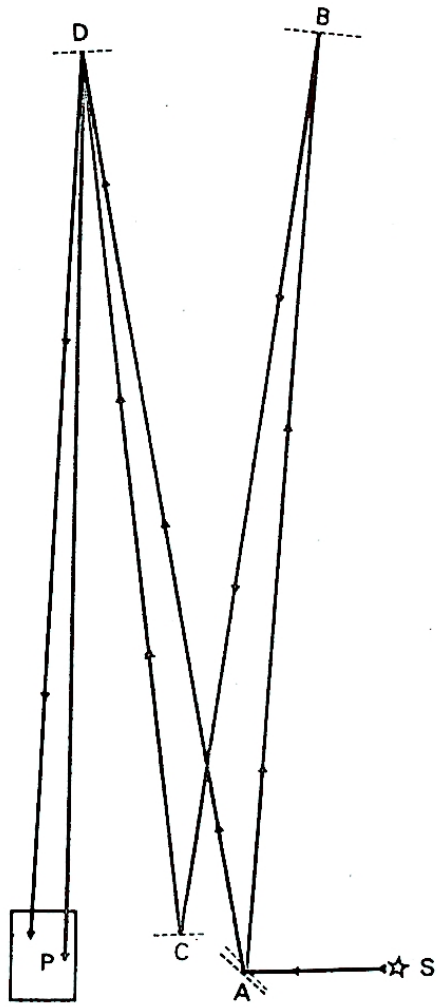


Figure 1 Layout of apparatus for measuring the speed of light.

Calculation of speed of pellet

If momentum is conserved then (mass of pellet) x (speed of pellet) = (mass of glider + pellet) x (speed of glider + pellet).

Mass of pellet $= 0.92\ gm$
Mass of glider $= 494\ gm$

Speed of glider $= \frac{1}{4.6}\ ms^{-1}$

$\therefore$ *Speed of pellet* $= \frac{494.9}{0.92} \times \frac{1}{4.6}\ ms^{-1}$

$\approx 117\ ms^{-1}$

Main sources of systematic error might have included: friction and air-resistance effects; increased mass of glider as more pellets were fired into it; calibration error of stopwatch; measurement of length of 1 m.
Main sources of random error might have included variation in mass of pellet; timing errors; draughts; variation in air-gun performance.

TABLE 1

Time (nano seconds)	Height of curves (arbitrary units) A	B	Time (nano seconds)	Height of curves (arbitrary units) A	B
0	3 090	3 147	21	3 092	3 075
1	3 078	3 189	22	2 992	2 612
2	3 076	3 127	23	2 894	1 580
3	3 059	3 104	24	3 015	860
4	3 054	3 091	25	2 967	921
5	3 047	3 087	26	2 842	1 491
6	2 995	3 094	27	2 876	2 022
7	2 639	3 080	28	2 985	2 421
8	1 716	3 070	29	3 098	2 522
9	932	3 041	30	3 023	2 617
10	737	3 021	31	2 982	2 900
11	1 169	3 039	32	3 136	3 059
12	1 626	3 076	33	3 078	3 045
13	2 162	3 100	34	3 069	2 906
14	2 314	3 095	35	3 014	3 056
15	2 428	3 083	36	2 951	3 223
16	2 679	3 083	37	2 971	3 039
17	2 870	3 086	38	3 021	2 976
18	2 875	3 085	39	3 006	3 090
19	2 773	3 089	40	2 918	2 982
20	2 902	3 105			

Calculation of momentum conservation experiment

Before the collision:
Momentum of larger glider $= 0.4 \times 0.48\ kg\ ms^{-1}$
$= 0.192\ kg\ ms^{-1}$

Momentum of smaller glider $= 0$

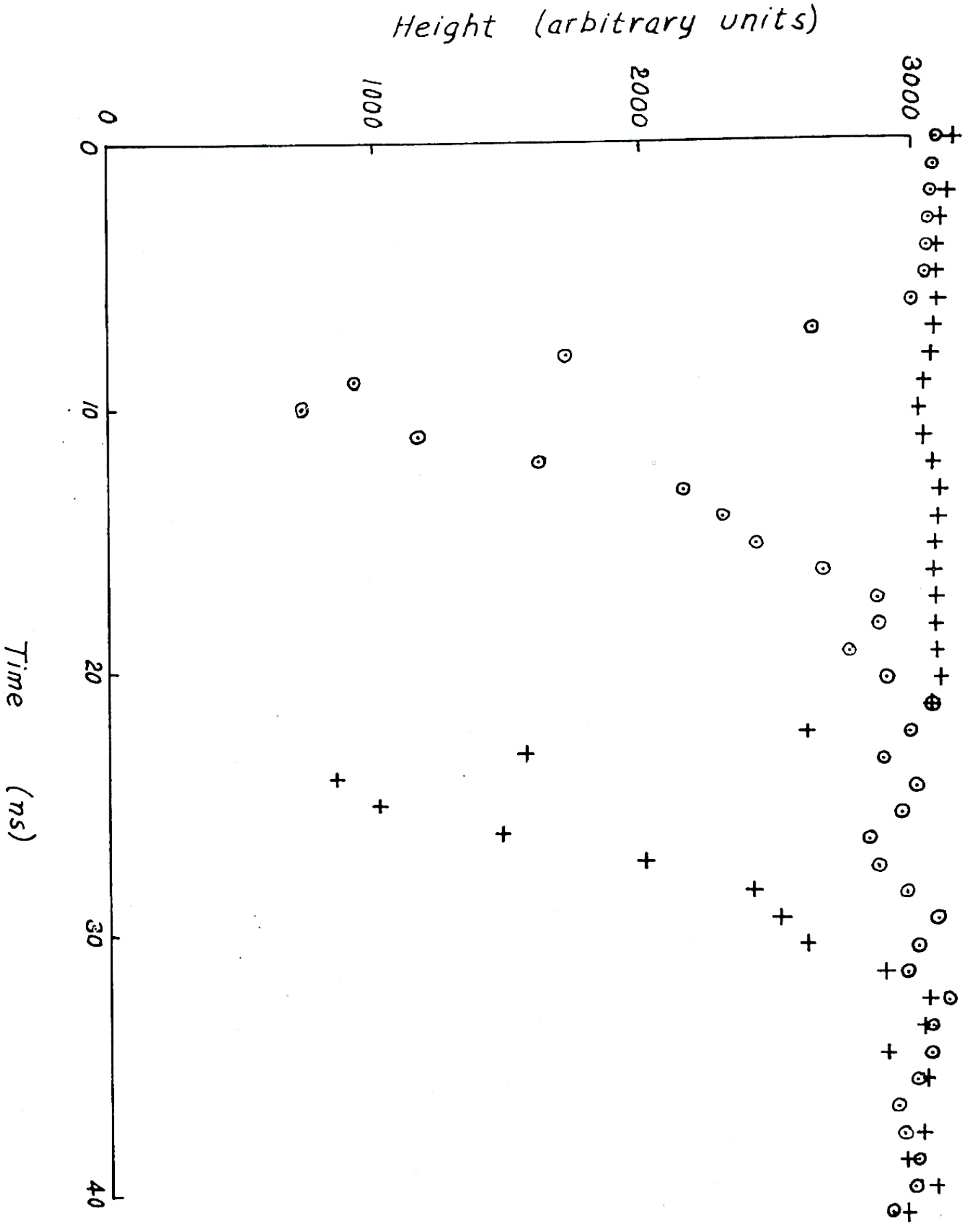
$\therefore$ *Total momentum* $= 0.192\ kg\ ms^{-1}$

After the collision:
Momentum of larger glider $= 0.4 \times 0.16\ kg\ ms^{-1}$
$= 0.064\ kg\ ms^{-1}$

Momentum of smaller glider $= 0.2 \times 0.62\ kg\ ms^{-1}$
$= 0.124\ kg\ ms^{-1}$

Total momentum $= 0.188\ kg\ ms^{-1}$

This is equal to the total momentum before the collision, within the estimated limits of error of 10% in the timings. So momentum was conserved in this collision.


Height (arbitrary units)
0
1000
2000
3000
Time (ns)
0
10
20
30
40

TELEVISION UNIT 4

Pre-broadcast Notes

The programme will deal with two distinct topics: electromagnetic forces and the representation of a field by a 'rubber membrane model'.

Subjects
1 Electromagnetic forces
2 Representing fields
Speakers
Dr A. J. Walton
Professor F. R. Stannard

1 Electromagnetic forces

Professor Pentz will introduce the programme by demonstrating qualitatively the interaction between two parallel brass rods which are connected to a pair of motor-car batteries.
Dr Walton will then demonstrate that 'something' does flow in conducting wires connected to a source of electrical current such as a battery, and that this 'something' can be collected on a pair of conducting spheres which then attract each other even after the current has ceased flowing.
As these demonstrations closely parallel the text material, it is essential that you read Section 4.2.2 of the Main Text before viewing the programme. It will also be helpful to have the text to hand while you view the programme – you may wish to refer to Figures 2, 6 and 7 during the broadcast.

2 Representing fields

Dr Stannard will use a 'rubber membrane model' to demonstrate one possible representation of an electrostatic field, and he will show how this idea can be used to illustrate the motion of electrons in a cathode-ray tube. In fact the elevation of the rubber membrane simulates potential energy (which is the main topic of the radio component of this Unit). The local slope of the rubber surface determines the force on the balls, i.e. the slope represents the field. You are advised to re-read Sections 2.5.5 and Appendix 3 of Unit 2 and to read Section 4.3.1 of the Main Text of the present Unit before the broadcast.

Post-broadcast Notes

1 Summary of the programme

In the demonstration of an 'electrodynamic' or 'magnetic' interaction between two current-carrying conductors, Professor Pentz showed that there was an interaction only if *both* conductors were connected to the batteries, and that the force was attractive if both were connected to the batteries in the same sense, but repulsive if the connection to either battery was reversed (interchanging the + and – connections).
If we accept that 'something' (electrical charges in fact) flows in a conductor connected to a battery, this demonstration showed that there was a force only while the charge flowed, that is, only while there was *motion* of electrical charge relative to the laboratory frame. Hence the term 'electro-*dynamic*'.

Dr Walton then demonstrated that if a 'paddle-wheel tube' is incorporated in an electrical circuit it behaves in a way which suggests that something does flow in the wires. By connecting two conducting spheres (graphite-coated ping-pong balls were used for this demonstration) to the source (a high-voltage supply, 6kV, equivalent in effect to a large number of car batteries), Dr Walton then showed that whatever flowed in the wires could be collected on the spheres and that the spheres attracted each other even after the current had stopped. This, of course, was an electrostatic attraction between positive and negative charges on the spheres. The experiment does not 'prove' that

negatively charged particles pass through the tube. It is, however, one possible interpretation of the experiment, and perhaps the most direct interpretation. In the second part of the programme, Dr Stannard used a 'rubber membrane model' to demonstrate how charged particles can be deflected and focused by an electrostatic field. In such a model, the gravitational potential energy of rolling. spheres simulates the electrostatic potential energy of charged particles; a change in height of the spheres represents a change in electrostatic potential. The rubber membrane provides a suitable surface for the spheres to roll on, and when it is raised in one place (or in several) to simulate the insertion of an electrode (or electrodes) the membrane stretches in such a way as to make the gravitational potential energy approximately proportional to the corresponding electrostatic potential energy.

The programme ended with a rubber membrane model of electron motion in a cathode-ray tube.

2 Follow-up

It will be useful revision to read Section 4.2.2 as soon as possible after viewing the programme.

3 Comment

Just a word of warning about rubber membrane models of electrostatic fields. Remember that what you saw was a *model*. It was intended to help you visualize the *idea* of a field, which, as you may recall from the main text, is a concept that is useful for describing 'action at a distance' and for simplifying calculations.
Perhaps this is the moment to read Section 4.3 of the Main Text once more.

TELEVISION UNIT 5

Pre-broadcast Notes

Subject
States of matter
Speakers
Professor M. J. Pentz,
Professor G. F. Elliott,
Dr A. J. Walton

What is it that determines whether a material, at a given temperature, will be a solid, a liquid, or a gas? It is the competition between the *binding energy* of the atoms and their *kinetic energy*. The latter, as you have seen in Unit 5, is a measure of the temperature of the system. The velocity distribution of the motions of the atoms in a gas (in an equilibrium condition) is called the Maxwell distribution (sometimes the Maxwell-Boltzmann distribution).

In the first part of the programme, Dr Walton will use a mechanical simulator to demonstrate how the changes of state from solid to liquid and from liquid to gas depend upon the competition between binding energy and kinetic energy. He will also demonstrate liquid and gaseous diffusion.

In the second part of the programme, Professor Elliott will show the 'Brownian motion' of small particles in suspension, and will use the air-table to explain it in terms of a mechanical analogy. He will show an experiment to measure the Maxwell distribution directly.

Post-broadcast Notes

1 Summary of programme

Professor Pentz introduced the programme using the example of ice, water and steam to pose the question 'Are the attractive forces holding the ice together being progressively weakened as the temperature is increased to form water and then becoming strongly repulsive in steam?'

Dr Walton refuted this view with a simple mechanical simulator for a solid,

using oily steel ball-bearings to build up a regular array, a lattice. Removing the outer bearings the array showed the smooth edges of a crystal lattice. Walton introduced a film sequence showing how such an array breaks up as the tray containing the ball-bearings is agitated from side to side at increased speed. This corresponds to the melting of a solid as the temperature rises. The model having reached the liquid state, some painted ball-bearings were added and their motion shown in slow motion.

The slow diffusion of the white balls into the others on the tray was seen to be typical of a liquid diffusion process by comparing it with an example of two liquids mixing in the studio.

Walton next posed the questions 'What happens when the kinetic energy exceeds the binding force? Does this happen in a gas?' A demonstration of the diffusion of a gas (bromine) showed that the process is very fast, much faster than liquid diffusion. How fast? And are all the atoms moving at the same speed? With the help of the simulator Walton showed that it is possible to get quite a good idea as to how many atoms are moving with what speeds. Using the technique of stroboscopic photography it is possible to record the successive positions of the simulated atoms at regular time intervals; from this the speeds of individual 'atoms' can be found, and when this is done for a large number of them (this could involve several strobe photos) enough data are obtained to construct a number-against-speed graph for the system. Although the simulator only gave information about 'atoms' moving in two dimensions, the resulting averaged velocity distribution for many ball-bearings showed a striking resemblance to the theoretical Maxwell distribution which strictly applies to a three dimensional system.

Professor Pentz then introduced Professor Elliott, Professor of Physics at the Open University.

After briefly outlining the structure of the course, Elliott showed you a fascinating example of a phenomenon due to the random motion of millions of atoms or molecules on relatively large (and visible under the microscope) particles. This is now called Brownian motion, after the British botanist, Robert Brown, who first recorded the effect. A mechanical analogy using pucks on the air-table showed the underlying reason for the random motion of the particles.

Referring back to Walton's simulation of the gas state, Elliott asked the question 'Can we measure the velocity distribution of atoms directly?'

A jet of water fired horizontally at a vertical plate of glass a foot or so away from the nozzle, strikes the plate at a level that depends on the speed of the jet. The slower the initial speed of the water the more does it fall before it reaches the plate.

This principle was used to determine the velocity distribution inside a hot oven containing potassium vapour. The atoms emerged in a stream from a small slit in the oven and fell under gravity. They were detected by a hot wire which caused them to ionize and to give a current output from the detector. A film showed the apparatus and a couple of results being taken. (Of course, the whole apparatus had to be under high vacuum, otherwise the potassium atoms would have been scattered by other atoms in their path, and the experiment would have failed). Notice that even the fastest atoms fell sufficiently over the length of the apparatus so as not to be detected in a horizontal line of sight from the oven slit. Elliott showed a schematic view of the apparatus and then the sort of curve which results. In fact this apparatus is capable of giving results very close to the ideal Maxwell distribution for a perfect gas.

TELEVISION UNIT 6

Pre-broadcast Notes

Subjects
1 The charge on an electron
2 The mass spectrometer
Speakers
Professor M. J. Pentz
Professor F. R. Stannard
Dr R. A. Ross

1 The programme
The Unit this week is about atoms and the sub-atomic particles from which they are built up. The television programme shows in action two pieces of apparatus which contributed to the study of the fundamental properties of these particles: first Millikan's oil drop experiment, which showed that electric charge has an elementary unit, that is, a minimum possible value, and that all larger electric charges are made up of multiples of this elementary unit (it also made it possible to measure the value of this elementary unit of electric charge); second, the mass spectrometer, which makes it possible to measure the masses of ions formed from atoms and molecules.

2 Background theory
For the first half of the programme, remind yourself from Unit 4 of the force (F) on an electric charge (Q) in a field (V). This is

$$F = QV$$

You will be watching small oil drops falling in air. The drops are so small that air resistance becomes significant and their speed of fall depends upon their mass and size.
For the second half of the programme, it is suggested that you read at least once the material in Sections 6.1, 6.1.1, 6.1.3, 6.1.4, 6.2, 6.2.2, 6.2.3 and 6.2.5, particularly the description of the mass spectrometer in Section 6.2.5.

3 Instructions to student
During the demonstration of the Millikan experiment, you will be watching microscopic drops of oil floating in an electric field, and it is suggested that for maximum clarity the viewing room should be darkened, and the brightness of the picture turned down a little.

You will also be asked to take some readings from a voltmeter (on the screen) during that part of the programme, *so have a pencil and paper ready*.

Towards the end of the programme Figure 1 (p. 21) is referred to and you should have it handy so that you can note some information on it.

When Professor Pentz introduces the part of the programme about the mass spectrometer, he shows how an electron beam is bent by a magnetic field by holding a magnet near a television screen. You can, of course, try this at home, although it needs a strong magnet to get a good effect. *But do not try it on a colour television set*; the metallic shadow mask inside the tube may become permanently magnetized and produce gross distortion of the picture. This is difficult to rectify!

Post-broadcast Notes

1
The experiment performed by Dr Stannard consisted of watching the behaviour of a tiny drop of oil in an electric field. If the oil drop carries no electric charge, or if it does but the field is turned off, then the drop will fall at a rate depending on its size and weight, because of the air resistance. If the oil drop carries an electric charge, then it will also experience a force due to the electric field between the plates. The value of the force depends on the

size of the charge and the strength of the field, and is given by QV for a charge of Q and the field of V. This force could make the oil drop fall more rapidly or make it rise, depending on its direction and strength. If the electric field is varied until the drop neither rises nor falls, then the downward force due to gravity must be the *same* as the upward force due to the electric field. It does not matter where the drop stops because the electric field is uniform. This is the basis of Millikan's experiment.

In the television demonstration Dr Stannard showed the apparatus and the balancing of a drop by varying the voltage applied to the plates in the apparatus. Four balancing sequences were shown. Between each balancing the charge on the drop may or may not have been changed using the small radioactive source to cause local ionization of the air molecules in the equipment. You were asked to note the voltage needed for balance on each occasion. Call them V_1, V_2, V_3, V_4. The following voltages needed to balance the *same* drop were also recorded during the same experimental run:

$$V_5 = 162, V_6 = 90 \quad V_7 = 159, V_8 = 130, V_9 = 161, V_{10} = 80$$

The electrostatic force needed to balance the *same* drop against gravity must always be the same, and this force is proportional to the voltage, V, multiplied by the charge on the drop.

These are the sort of readings taken by Millikan and below we pose the sort of questions he asked himself when he first did the oil drop experiment in 1913. At a later date he was able to find an absolute value for the charge of the electron by calculating the actual downward force due to gravity which had to be balanced by the electric field. The present accepted value for e is $(1.60210 \pm 0.00007) \times 10^{-19}$ coulomb. Nowadays, instead of using oil drops it is possible to use very small plastic balls whose size and weight can be measured accurately. Nobody has been able to show, practically or theoretically, that a smaller unit of charge exists.

Let us suppose there is an elementary unit of charge, e. Each drop would then carry only an integral number, n, of elementary units of charge so the charge on the drop would be ne and the force on the drop at each balancing would be neV. When the drop is balanced this upward force is equal in magnitude to the constant weight of the drop. Thus,

$$neV = F_g$$

where F_g is the force due to gravity.

For a particular set of readings obtained using just one drop the force due to gravity must be the same; so any change in the total charge must be compensated by a change in the applied voltage such that

$$neV = \text{constant}$$

If the elementary charge, e, is fixed then

$$nV = \text{constant}$$

In order to demonstrate that there is indeed an elementary unit of charge you are required to choose a set of integers, n, such that nV is a constant for all ten readings. Naturally, with enormous values of n you could satisfy the relation for any ten voltages chosen at random! So, to prove the elementary nature of the charge values of n should be *small*. (Bear in mind that the six Values $V_5 \ldots V_{10}$ are just as much subject to experimental errors as your own readings.)

Work out the values of n for the ten readings above. If the drop had carried only one electron, what voltage would have been needed to balance it?

Set out your readings in the table below:

Reading	V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}
Voltage					162	90	159	130	161	80
n										
Voltage for $n = 1$ would be:										

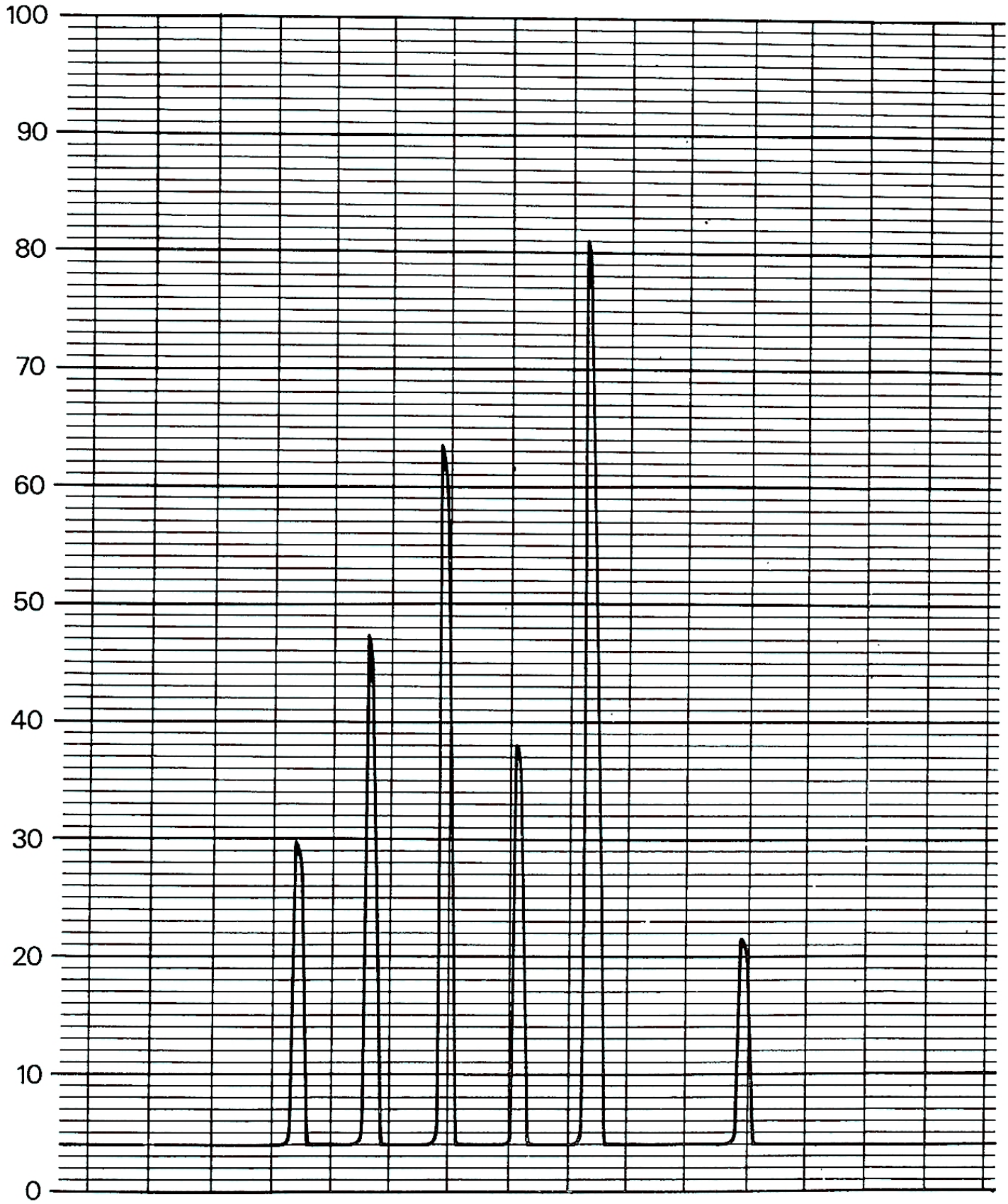
These questions will be answered in the supplement to the Television Notes to Unit 6 which you will find on p. 22.

2

The second half of the programme was about the mass spectrometer. Dr Ross used a simple mechanical analogy to show how charged particles moving through a magnetic field are separated according to their mass. A diagram similar to Figure 3 (Section 6.2.5) of the Main Text was used in the programme to show the basic layout of a mass spectrometer. After showing the parts of a small mass spectrometer, there was a film of an operational run on a larger mass spectrometer at University College, London. At the end of the film a mass spectrum was plotted and this is included here as Figure 1. As Dr Ross explained in the programme each peak shows the ion current due to ions of different masses, the masses in general being approximately 1 relative atomic mass unit apart. One of the peaks represents mass 200. Dr Ross showed you which one. The height of the peak, which represents the ion current, is a measure of the relative abundance of ions of that mass. So using the mass 200 peak as a start, deduce the ion masses represented by the other peaks and their relative abundances. Then, assuming that the six peaks refer to the six isotopes of one element, calculate the relative atomic mass of that element and decide what the element is. Use the same method for the calculation as that outlined at the end of Section 6.2.5.

Professor Pentz briefly outlines the results at the start of the television programme for Unit 7, and you will find the answer fully worked out on p. 27.

Figure 1



UNIT 6 TELEVISION SUPPLEMENT

Millikan's Experiment

This problem could have given you some trouble. It is not as easy as it looks. Your completed table would have been like this.

V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}
214	126	124	91	162	90	159	130	161	80

What we then did was list the voltages in order and group them, allowing for experimental errors. We obtained five different readings this way from the ten listed above. Then, with these five readings of voltage and assuming that a smallest charge, e, exists, you have (see the Television Notes for Unit 6):

$$nV = \text{constant}.$$

The larger V is, the smaller n, the number of elementary charges on the drop, must have been. Putting the equation in terms of n

$$n = \frac{\text{constant}}{V}.$$

So n is a function of $\frac{1}{V}$. We drew up a table of $\frac{1}{V}$ for the five readings. Now the smaller $\frac{1}{V}$ the smaller n must have been. We then used a trial and error method to try and determine n. The reasoning went as follows. Try making the smallest value of $\frac{1}{V}$ correspond to $n = 1$ so divide the other values of $\frac{1}{V}$ by the smallest value. Then try $n = 2$ for the smallest number of charges on the drop $\left(\text{smallest } \frac{1}{V}\right)$ and divide all the $\frac{1}{V}$ readings by the smallest divided by 2. For $n = 3$ divide all the $\frac{1}{V}$s by the smallest $\frac{1}{V}$ divided by 3. Similarly, for $n = 4$, etc.

If you were unable to get an answer to the problem, why not try the above procedure to see what you get. Our working is below.

Our table for the trial and error procedure was as follows:

V	$\frac{1}{V}$	For convenience $10^4 \times \frac{1}{V}$	Try $n = 1$ i.e. $\div 47$	Try $n = 2$ i.e. $\div \frac{47}{2}$ i.e. 23.5	Try $n = 3$ i.e. $\div \frac{47}{3}$ i.e. 15.67	Try $n = 4$ i.e. $\div \frac{47}{4}$ i.e 11.75
80	0.0125	125	2.66	5.32	7.98	10.64
90	0.0111	111	2.36	4.72	7.08	9.45
127	0.0079	79	1.68	3.36	5.04	6.72
161	0.0062	62	1.32	2.64	3.96	5.28
214	0.0047	47	1	2	3	4

So, using the value $n = 3$ for the smallest number of elementary charges gives the best results, and the numbers of elementary charges on the drops were 3, 4, 5, 7 and 8. If there were only 1 elementary charge, i.e. for $n = 1$, $10^4 \times 1/V$ would be $47 \div 3$ i.e. 15.67.

$$\text{So } \frac{1}{V} = 15.67 \times 10^{-4}$$

$$\text{So } V = \frac{10^4}{15.67} = 638 \text{ volts.}$$

Answers to the questions posed in the Millikan experiment:

Number of elementary charges on the drop – 3, 4, 5, 7 and 8
Voltage for 1 elementary charge – 638 volts.

TELEVISION UNIT 7

Pre-broadcast Notes

1 The programme
The first part of this programme is about absorption of light and you will see some examples of this demonstrated. The lines in the visible region of the emission spectra of sodium are examined briefly and then you are given a glimpse of molecular spectroscopy. Finally, a direct method determining ionization energies is shown.

Subjects
1 Emission and absorption spectra
2 Ionization energy
Speakers
Professor M. J. Pentz
Mr W. Coates
Dr J. Callomon
Dr R. A. Ross

2 Background
During the programme Dr Ross makes a (filmed) visit to Dr J. Callomon, a molecular spectroscopist at University College, London. This part of the programme is mainly to give you a glimpse of this field so do not worry about the detail. Some of the terms will be unfamiliar to you but you should be able to follow the general story without understanding these. The last part of the programme is about ionization energies. You should remind yourself of how we defined this in Unit 6 (Section 6.5.6).

3 Instructions to students
During this programme you will see demonstrated spectral line emission and absorption phenomena. These effects are difficult to see (even in the studio) so it is strongly recommended that the viewers' room be darkened and the controls of the TV receiver adjusted to give slightly reduced brightness and higher contrast than normal.

The programme starts with Professor Pentz outlining the results you should have obtained from the mass spectrometer trace given in the TV programme of Unit 6. You will find all these results and calculations in the supplement to this Unit's Television Notes, which is on p. 27, so do not bother recording them in detail – just note the final relative atomic mass.

Post-broadcast Notes

Professor Pentz performed some simple demonstrations of absorption of light. First mercury light was shone through an open glass beaker containing mercury. The mercury vapour (only one atom of mercury to 1 000 000 air molecules) absorbs the light so efficiently that a shadow of the vapour above the mercury liquid was seen on a specially prepared screen. When a sodium light was used no vapour shadow was visible. Sodium light was then shone through a bunsen flame and when traces of sodium were vapourized in the flame the light absorbed by the sodium cast a shadow on the screen. Mercury light gave no such shadow. This is a convincing

demonstration that the best absorbers of light radiation from any given lamp are atoms of the same kind as those used in the lamp.

Mr W. Coates of the Royal Institution then pointed out the main features of a simple spectroscope (Fig. 1) and showed how a prism makes the image of a slit (illuminated by white light) move to one side and disperse into a continuous spectrum. A similar spectroscope (adjacent to the white light spectroscope) showed how the image of a slit illuminated by a sodium lamp is only displaced by the prism. In other words, sodium light must be virtually just one frequency. The white light spectrum was then switched on so that the relative position of the intense yellow sodium line could be seen (Fig. 2).

Figure 2 is on Plate A, facing p.81.

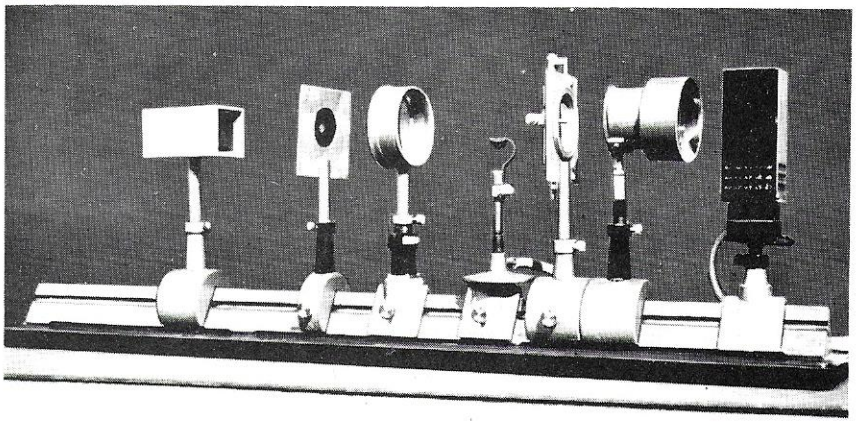


Figure 1 A simple spectroscope arrangement.

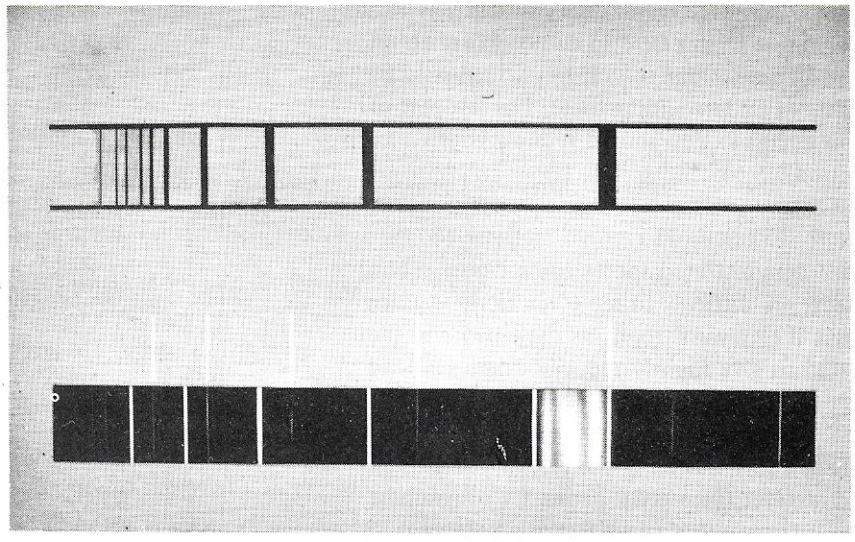


Figure 3 The emission spectrum of sodium (visible region) and the Balmer series of hydrogen.

The absorption experiments were then performed. First the yellow sodium line on the screen was made to 'go out' by fully absorbing the sodium light by the relatively cooler sodium vapour produced by dipping a sodium 'pencil' into the bunsen flame. In order to prove convincingly that the sodium vapour was absorbing rather than stopping the sodium light, the experiment was repeated, this time using white light as the source. Dr Ross then showed the full sodium spectrum and isolated some lines of the Sharp series, which look very similar to the Balmer series of hydrogen (Fig. 3). Dr Ross then talked (on film) to Dr John Callomon, a molecular spectroscopist at University

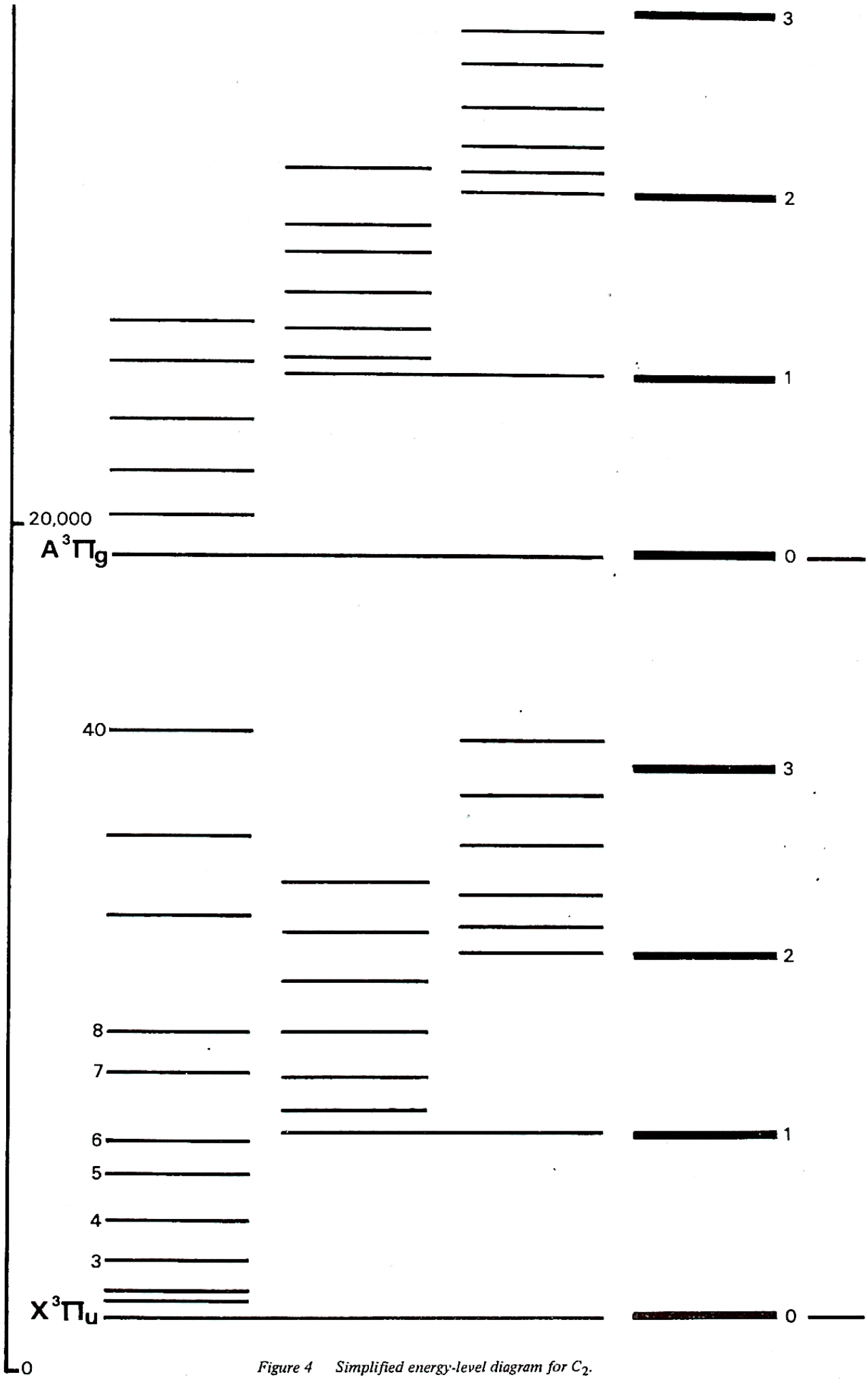


Figure 4 Simplified energy-level diagram for C_2.

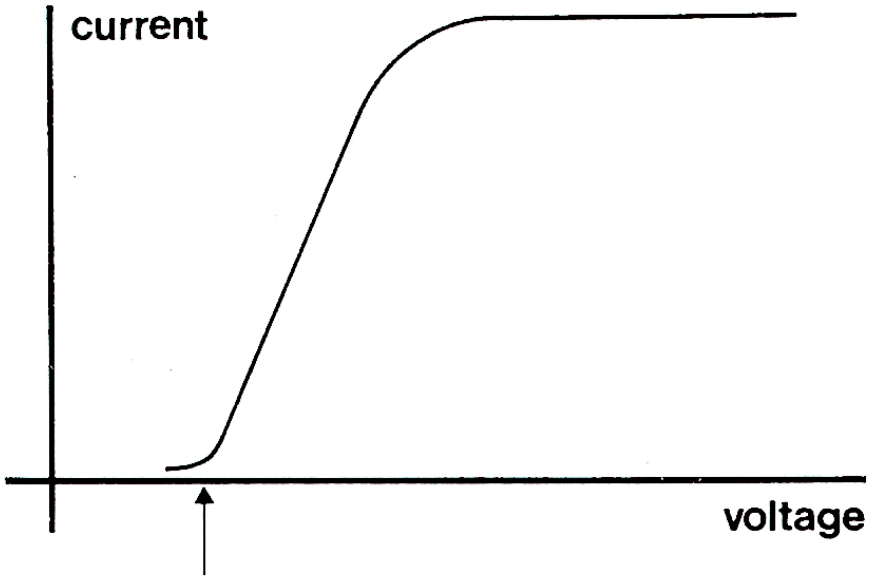


Figure 5 Determining ionization energy in a mass spectrometer.

College, London. You saw his apparatus briefly and then the analysis of the spectral lines on a photographic plate. Do not worry too much if you did not follow the whole argument, but you should see that even in a complex molecular spectrum one goes from spectral lines to energy levels.

The simplified energy-level diagram that you saw (Fig. 4) consists of three types of energy levels. The overall spectrum (the green band) is in the visible region and its position is due to an electron energy jump, as Dr Callomon pointed out. The lines spaced at each electronic energy level (labelled 0, 1, 2, 3 on the right) are due to the vibrational energy of the molecule. So vibrational energy is also quantized and the levels have quantum numbers associated with them. The lines closer together, drawn as 'stacks' on the left-hand end of the vibrational levels, are due to the rotation of the molecule, so rotational energy is also quantized and has associated quantum numbers. It was the vibrational and rotational quantum numbers that Dr Callomon referred to on the high resolution spectrum.

Figure 4 is on p. 25.

In the last part of the programme Dr Ross reminded you of the ionization reaction:

$$e + M \rightarrow M^{+} + 2e$$

occurring in the source region of a mass spectrometer. He then demonstrated ionization of a gas in a small valve. Increasing the energy of the electron beam caused only a slight increase in current until the critical voltage was reached when the gas conducted strongly. The current then rapidly increased and a visible glow was seen in the tube. Dr Ross then drew the type of curve (Fig. 5) that is obtained when ionization energies are determined in a mass spectrometer. He showed how the 'straight' portion of the curve is extrapolated to determine the voltage from which the ionization energy is calculated.

UNIT 7 TELEVISION SUPPLEMENT

The Mass Spectrum

The first step in identifying the element giving rise to the spectrum is to decide the mass number of the ions responsible for each peak. Given the value 200, the others are readily labelled 198, 199, etc. with a gap at 203. The heights of the peaks are then measured, first establishing a base line. The actual scale used is irrelevant (we quote values in centimetres), as it is only relative heights that are important. The relative heights are in fact the relative abundances of the ions. The percentage relative abundances are multiplied by the mass of each ion and then the relative mass of the sample is obtained using the procedure outlined in the main text of Unit 6.

Our table of results is as follows:

Mass	198	199	200	201	202	203	204
Height	5.46	9.15	12.57	7.20	16.27	0	3.20
% Relative height	10.14	16.99	23.34	13.37	30.21	0	5.94
$\frac{\text{\% Relative height} \times \text{Mass}}{100}$	20.08	33.81	46.68	26.87	61.02	0	12.12

The relative Atomic Mass (200.58) identifies the element as mercury.

Some comment on this result is called for. You probably noticed the small peak at mass 196 which should affect the result. You are also no doubt aware that the actual values of the masses of the ions are not exactly whole numbers. Another unjustified assumption in the above calculation is that the sensitivity of the instrument is the same for all these masses. All these assumptions involve small errors in the calculation. The closeness of the result to the actual value suggests that these errors, while small, to some extent compensate each other.

TELEVISION UNIT 8

Pre-broadcast Notes

In the first half of the programme we carry out some simple physical and chemical experiments to show you how the Periodic Table classifies the elements into:

(i) chemical families whose members have the same general properties but also show a regular gradation of these properties within the group. The examples taken are Group I, the Alkali Metals; and Group VII, the Halogens;

(ii) broader groups such as Metals and Non-metals.

Subjects
1 The Periodic Table
2 Ionic and Covalent Compounds

Speakers
Professor M. J. Pentz
Professor L. J. Haynes
Dr D. Johnson

In the second half of the programme we look at electrovalent and covalent compounds. Once again we perform some simple experiments which show how these types of compounds differ. The results are then related to the types of bonding occurring in the compounds.

Post-broadcast Notes

In the first part of the programme you were shown two important demonstrations:

(i) the first demonstration showed the reactions of the alkali metals with air and water. The metals combine with the oxygen of the air, and they react with water in accordance with the equation,

$$2M + 2H_2O \rightarrow 2MOH + H_2$$

(M can be any one of the five metals, lithium, sodium, potassium, rubidium and caesium),

(ii) the second demonstration showed the reaction of the halogens with phosphorus. The products of the reaction do not necessarily have the same formula type, although they are all phosphorus halides. The elements examined were fluorine, chlorine, bromine and iodine.

Fluorine gives almost exclusively the pentafluoride, PF_5, while iodine gives the tri-iodide, PI_3. Chlorine and bromine yield a mixture of the trihalide and pentahalide the composition of which depends on the conditions.

Although red phosphorus did not appear to react with iodine in our demonstration at room temperature, there is, in fact, some reaction and this is more obvious if the reaction is carried out at a higher temperature. This emphasizes the importance, when making comparisons, of ensuring that the experimental conditions are identical. In our *qualitative* experiments, the conditions were not identical; we were, for example, comparing the reaction between two solids with that of a solid and a gas.

In the second half of the programme, the volatility of carbon tetrachloride and carbon tetrabromide was demonstrated, and the involatility of sodium chloride and sodium bromide. Then you were shown that liquid sodium bromide conducts while liquid carbon tetrachloride does not. Of course, we had to heat the sodium bromide to melt it, while carbon tetrachloride was already liquid, so the comparison was not made at the same temperature. This may seem slipshod, but nevertheless, historically it was the kind of experiment from which the distinction between ionic and covalent compounds grew up.

Perhaps you noticed the discolouration in the molten sodium bromide during conduction of the electric current. This is caused by decomposition products; sodium metal is formed at one platinum wire and bromine at the other.

Finally, we related the differences in volatility and conductivity observed for the sodium and carbon halides to differences in structure.

TELEVISION UNIT 9

Pre-broadcast Notes

Subjects
1 A model Castner Cell
2 Neutralization and pH
Speakers
Professor M. J. Pentz
Dr R. A. Ross
Dr D. Johnson

1 The programme

The programme is divided into two parts. There is a short initial piece on an industrial application of electrolysis – the preparation of chlorine and sodium hydroxide by the electrolysis of sodium chloride solutions.

The second part examines in detail the neutralization reaction between an acid and an alkali. It shows first that this reaction can be used to compare the concentration of an acid and an alkali, and then examines the variation in pH during neutralization reactions using strong and weak acids. These experiments are used to discuss the strength of acids and buffer solutions.

2 Instructions to Students

During the programme you will be expected to take two readings from a tall glass tube called a burette. These readings record the level of the solution of an acid in the burette. The surface of the liquid is curved (Fig. 1) and you should read the level of the base of the dark portion of the curve. In Figure 1, the level obviously lies between 12 and 13, and one fairly experienced chemist took the reading 12.46.* It is not possible to be confident about the second decimal place, but one should always try to record it. Your first

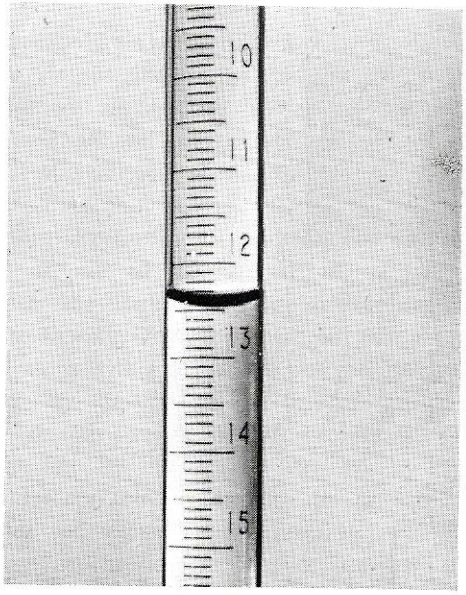


Figure 1 The liquid surface in a burette.

reading should go into the space opposite 'Initial Reading' in the table below, and the second into the space against 'Final Reading'.

Initial Reading	
Final Reading	
Volume of acid (cm^3)	

The burette is graduated so that the difference between initial and final readings is the volume of acid removed from the burette in cm^3. You may have some difficulty in taking the second reading, so we tell you now that it lies between 27 and 28.

**Note that in the photograph the 12.4 division line is obscured by the dark part of the liquid surface.*

Post-broadcast Notes

A Summary of Programme

(i) Professor Pentz reminded you of the home electrolysis experiment and introduced Dr David Johnson.

(ii) Dr Johnson described a working model of the Castner process, the electrolysis of sodium chloride solutions. When the apparatus (Fig. 2) was switched on, bubbles of chlorine were generated at the anodes, while sodium dissolved in, and was carried away by, the mercury stream. The mercury stream encountered a counter-current of water in the lower part of the apparatus. The sodium in the mercury reacted with the water giving sodium hydroxide solution and hydrogen gas.

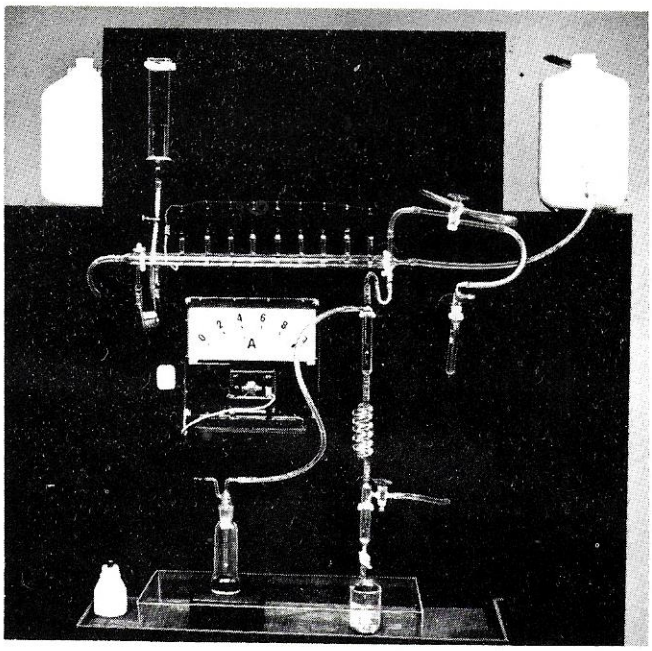


Figure 2 A laboratory model of the Castner process.

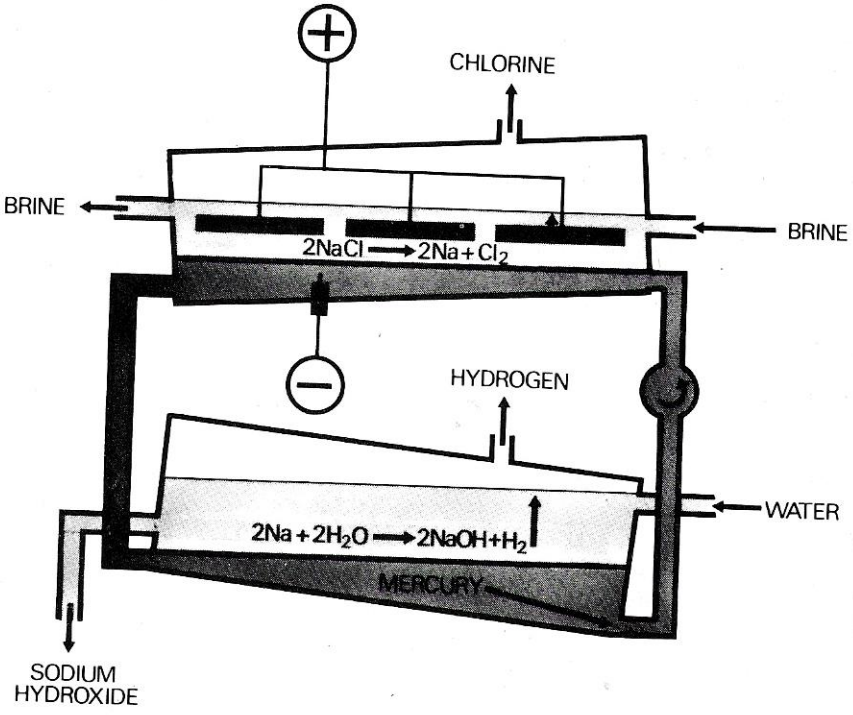


Figure 3 Schematic diagram of an industrial Castner cell.

Figure 3 shows a schematic diagram of a real industrial plant. The mercury cathode flows down the sloping floor of the upper of two tanks. Here sodium chloride is decomposed into sodium (this dissolves in the mercury) and chlorine gas which is evolved at the graphite anodes. The mercury flows into the lower tank where the floor is tilted in the opposite direction to that of the upper tank. Here it meets a counter-current of water and the sodium reacts to give sodium hydroxide solution and hydrogen gas. The alkaline solution is carried out of the lower tank in the water stream, while hydrogen and chlorine gases are tapped off at the exit points shown.

(iii) Professor Pentz reminded you of the home neutralization experiment and introduced Dr Johnson again.

(iv) Dr Johnson repeated your Home Experiment, but used measured quantities. He ran 0.100 M hydrochloric acid into 25.00 cm^3 of sodium hydroxide solution of unknown concentration until an indicator called bromophenol blue *just* changed from a dark to a pale colour. *Much more indicator than usual was added in the hope that you might see the colour change more clearly*. You should have taken readings from the burette and found the volume of acid needed for the neutralization. This enables you to calculate the concentration of the sodium hydroxide solution.

(v) Dr Bob Ross repeated this neutralization reaction, but used 0.1 M acid and 0.1 M alkali. He put alkali in the burette and followed the change in pH with the volume of alkali added. The curve that he obtained is shown in Figure 4. As 25.00 cm^3 of 0.1 M acid were put in the beaker, 25.00 cm^3 of 0.1 M alkali were needed for neutralization. The pH hardly changed at first, then shot up near the neutralization point (or end point). At the neutralization point the beaker contains just a solution of sodium chloride, so the pH is seven, the figure for water. The sharp change in pH near the neutralization point explains why the indicator changes colour so sharply. Dr Ross pointed out that a mixture of the acid and alkaline solutions with a pH of five was very difficult to make up or to keep, because tiny additions of acid or alkali caused large changes in the pH – the mixture is a very poor *buffer* solution.

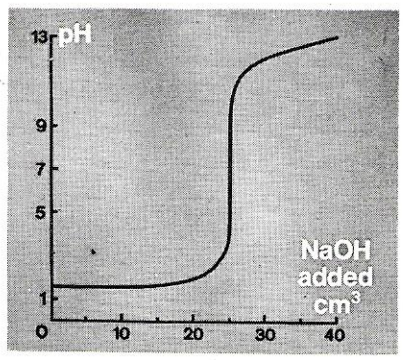


Figure 4 pH variation when 0.1 M NaOH is added to 25 cm^3 of 0.1 M HCl.

(vi) Dr Johnson used the reaction between calcium carbonate and acids to demonstrate that the vigour of the reaction with hydrochloric acid depends on the hydrochloric acid concentration. He then showed that the reaction with a strong acid is more violent than that with a weak acid of the same concentration. He concluded that it was hydrogen ion, rather than total acid concentration, that mainly determined the vigour of the reaction with chalk.

(vii) Dr Ross repeated his pH experiment using 0.1 M acetic acid instead of 0.1 M hydrochloric acid. The curve he obtained is compared with the previous one in Figure 5. The change in pH at the neutralization point is less dramatic but still substantial. Dr Ross pointed out that at a pH of 5 the slope of the curve is now very shallow, so this mixture of the acetic acid and sodium hydroxide solutions is resistant to changes in pH. He showed that the mixture is created by adding about half the alkali needed to neutralize the acid, so it consists of a mixture of solutions of sodium acetate and acetic acid. Thus, as discussed in the text, the mixture of a solution of a weak acid and one of its salts is a good buffer solution.

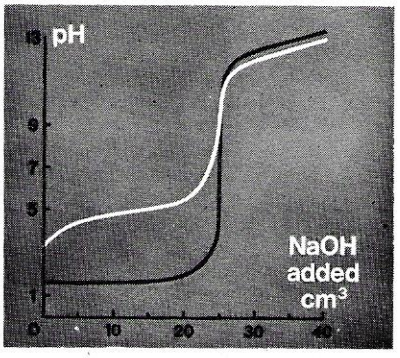


Figure 5 pH variation when 0.1 M NaOH acetic acid is added to 25 cm^3 of 0.1 M. Figure 4 is included for comparison.

Finally, Dr Ross pointed out that, although a particular volume of 0.1 M acetic acid had a much lower hydrogen ion concentration than the same volume of 0.1 M hydrochloric acid, the same volume of the alkali was needed to neutralize both. He asked you why, as hydrogen ions are neutralized in both reactions, this should be so.

B Data from Experiments

Dr Johnson's values for the burette readings are shown in the table below.

Initial reading	2.93
Final reading	27.25
Volume of acid (cm^3)	24.32

Thus 25.00 cm^3 of the NaOH solution are neutralized by 24.32 cm^3 of 0.100 0 M HCl.

So 1 litre (1000 cm^3) of the NaOH solution is neutralized by

$$\frac{1000 \times 24.32}{25.00} = 972.8 \text{ cm}^3 \text{ of } 0.100\ 0 \text{ M HCl.}$$

Now 972.8 cm^3 of 0.100 0 M HCl contain 0.09728 moles HCl.

So 1 litre of the NaOH solution is neutralized by 0.097 28 moles HCl.

But, in the neutralization reaction

$$NaOH + HCl \rightarrow NaCl + H_2O$$

1 mole NaOH reacts with 1 mole HCl.

Thus 1 litre of the NaOH solution must contain 0.097 28 moles NaOH.

The NaOH solution is 0.097 28 M.

Once you have understood this calculation, you can see that the concentrations of the two solutions are inversely proportional to the volumes which react. That is,

$$\frac{\text{Concentration of NaOH}}{\text{Concentration of HCl}} = \frac{\text{Volume of HCl}}{\text{Volume of NaOH}}$$

$$\text{Concentration NaOH} = \frac{24.32}{25.00} \times 0.100\ 0 \text{ M}$$

$$= 0.097\ 28 \text{ M}$$

TELEVISION UNIT 10

Pre-broadcast Notes

In this Unit's TV programme, we are going to look at two aspects of molecular shape.

Part 1 will involve a demonstration of how modelling balloons can predict the geometry of the arrangement of bonds around an atom.

Part 2 will be concerned with the concept of chirality and how we distinguish between chiral and achiral objects both on the macroscopic and molecular scale.

Text The following Sections of the text should be read before viewing the programme: 10.1, 10.2, 10.3, 10.4 (1–5), and Appendix 2.
One of the few physical ways of easily identifying a chiral substance is through the way it rotates plane-polarized light. We usually call this its 'optical activity'. The principle of using sheets of polaroid to detect

Subjects

1 Electron Repulsion Control of Molecular Shape
2 Chirality

Speakers

Professor M. J. Pentz
Dr R. R. Hill

the plane of polarization of a beam of light is explained in Appendix 2 of the text, and you should try the experiment mentioned before viewing the television programme. In the programme we use an instrument called a polarimeter to detect the sign of rotation produced by glucose solutions. A more sophisticated version of this instrument is normally used for quantitative work where the exact number of degrees of rotation is determined. This would be measured very accurately as would also the concentration of the glucose solution and the length of the light path through the solution. However, for our purpose a very simple polarimeter is enough as we only wish to determine the sign of rotation (+ or −) of the glucose solution.

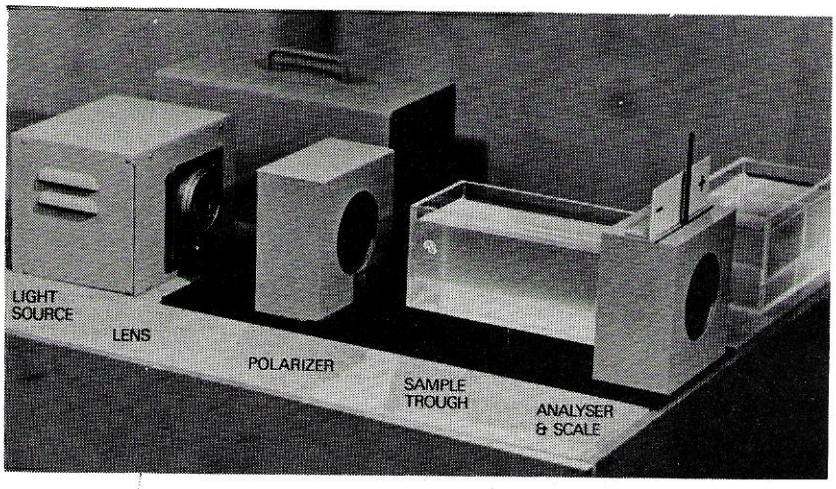


Figure 1 A simple polarimeter.

Figure 1 shows the instrument we use. Its basic parts are:

1 a *light source* which emits light of a very narrow range of wavelength;

2 a *lens* system to give a parallel beam of light (i.e. the beam does not diverge or converge);

3 a sheet of polaroid material – called the *polarizer* which converts the beam into a beam of plane-polarized light;

4 the *sample trough*—in which the plane-polarized light is rotated to the left or right according to the nature of the sample;

5 another sheet of polaroid called the *analyser*;

6 a *scale*, with a pointer attached to the analyser.

The procedure for measuring the rotation is first to set the analyser to the zero point on the scale and then, with no sample in the light path, to rotate the polarizer until complete cut-off of the light beam is achieved, i.e. until no light passes through. (This will be done before the programme.) We then know that at the zero position the axis of polarization of the analyser is at 90° to that of the plane-polarized light leaving the polarizer. Then we place the sample in position and move the analyser to the + or − side until cut-off is again achieved. The angle through which the pointer on the analyser has moved is the angle of rotation.

Post-broadcast Notes

Summary of Part 1

Long modelling* balloons can be twisted together to form an array of lobes about a central position. The overall shape spontaneously taken up by the group depends on the number of lobes. For any given number, the shape is that which allows the minimum mechanical repulsion between the surfaces where they come into contact near the central position. The

* *These are not just long balloons. They have been specially treated to allow them to be pinched without bursting. You may be able to obtain some through your local toy dealer or a 'novelties' shop.*

principle is precisely analogous to that which is thought to determine the shapes of covalent molecules. Each set of bonds around an atom assumes a geometry which allows minimum repulsion between them. The shapes of covalent molecules of the type AB_n determined by experiment match precisely those obtained by making an n-lobe array with modelling balloons. For instance, the compound sulphur hexafluoride, SF_6, has been shown to have the same shape as that obtained by twisting three modelling balloons together to give six equal lobes.

Summary of Part 2

We can divide all objects into one of two categories:

1 *achiral* – can be superimposed on its own mirror image;

2 *chiral* – cannot be superimposed on its own mirror image.

Chiral objects do not possess any symmetry. Achiral objects always do, by far the commonest being a plane of symmetry.

Chirality becomes very important at the molecular level. A mirror image related pair of compounds with a chiral structure are indistinguishable except for the way they rotate plane-polarized light. We showed, for example, that naturally occurring glucose rotates it to the right whereas glucose which has the mirror-image structure to the natural form (obtained by laboratory preparation) rotates it to the left. This makes the natural form, (+) glucose and its mirror form, (−) glucose. (You may have noted that in order to do the experiment properly we should have repeated the operations with a different concentration of sample. This is because there is no way of distinguishing a reading of +90° from −270°! However, at half the concentration the first would give us +45° and the second −135°.)

In other reading material you may come across the use of (d) and (l) or (D) and (L), associated with the names of optically active compounds. The lower case letters stand for the same as (+) and (−) respectively. The capital letters however refer to something quite different, and you should not assume that substances with names prefixed by these symbols rotate plane-polarized light to the right and left respectively.

Why do we invariably find that only one form of naturally occurring chiral compound is utilized by living organisms? Virtually all chemical processes in biological systems occur with the help of agents known as enzymes. If enzymes are chiral, they would be able to discriminate between a (+) and a (−) form of a compound in the same way that a left-handed glove (chiral) can distinguish between a left and a right hand ((+) and (−) forms of a hand). In general, a chiral object can only be distinguished from its mirror image by something which is itself chiral. Why then did life evolve based on organic molecules of which only the one form is used? Was there some pre-life chirality which favoured one form in each case or was it all a matter of chance?

Comment In using a cup to demonstrate what we meant by a plane of symmetry, the remark was made that such a plane would divide the cup into two *identical* halves. You may have perceived that this is not *strictly* true! The two halves are, in the case of a cup, non-superimposable mirror images of one another. Had we chosen a more simple object, such as a box, then a plane of symmetry would indeed have divided it into two absolutely identical halves.

TELEVISION UNIT 11

Pre-broadcast Notes

(i) The programme

The programme discusses the vibration and dissociation of a diatomic molecule and the reaction between an atom and a diatomic molecule. From these simple systems, we develop the theoretical ideas that are used to discuss the role of energy in chemical reactions. So as to avoid being entirely on a theoretical plane, the sign of the overall energy change in three reactions is determined in the studio. The programme follows the development in the text fairly closely. It deals with the material in Sections 11.2 and 11.3 with a short extension into Section 11.4.

Subject

Energy in Chemical Reactions

Speakers

Professor M. J. Pentz
Dr R. A. Ross
Dr D. A. Johnson

(ii) Instructions to students

It is strongly advised that you read Unit 11 up to the end of Section 11.3.4 at least once before viewing the programme.

Post-broadcast Notes

The programme followed the development in the text fairly closely, covering Sections 11.2 and 11.3 with a brief reference to 11.4.

Dr Ross started the programme by discussing the Morse Curve (Fig. 2 in the main text). He went into rather more detail than does the text, by relating the types of energy a diatomic molecule can possess to the Morse Curve. He emphasized that the Curve gives the potential energy of the atoms and showed how this turns into kinetic energy as the molecule vibrates with a given energy.

The atom plus diatomic molecule reaction was then dealt with, again giving more detail of what was happening than does the text. When the reaction had been discussed, it was related to the potential energy surface (Fig. 6 of the Main Text), which was broken along the most favourable reaction path, and the reaction co-ordinate was examined. Incidentally, there was a slip of the tongue when Dr Ross referred to the endothermic reaction; he said that the energy of the products was less than the energy of the reactants. It should, of course, be the other way round: for endothermic reactions the energy of the products is greater than the energy of the reactants. Dr Johnson then performed three reactions (two of which you had performed in the Home Experiment for Unit 9 and the third of which was like others in Unit 9). He examined the reactions so as to determine the direction of the overall energy change. A thermocouple was used to detect any change in temperature (the reagents being initially at the same temperature). An increase in temperature was taken as an indication that energy had been released, that is, that the reaction was exothermic and ΔH was negative.

The three reactions and the sign of their enthalpy change were:

Magnesium and hydrochloric acid

$$Mg(s) + 2H^+(aq) = Mg^{2+}(aq) + H_2(g)$$
$$\Delta H \text{ negative}$$

Sodium carbonate and magnesium sulphate

$$CO_3^{2-}(aq) + Mg^{2+}(aq) = MgCO_3(s)$$
$$\Delta H \text{ positive}$$

Sodium hydroxide and ferric nitrate

$$3OH^-(aq) + Fe^{3+}(aq) = Fe(OH)_3(s)$$
$$\Delta H \text{ negative}$$

Dr Ross then related the enthalpy change in a reaction to the reaction co-ordinate and told you that most reactions that occur readily at room temperature are exothermic.

Finally, the different ways energy plays a part in chemical reactions were illustrated by using a model borrowed from Dr Derek Fisher. The model (Fig. 1) consists of two compartments with a moveable partition between them. The 'product' compartment has an adjustable floor.

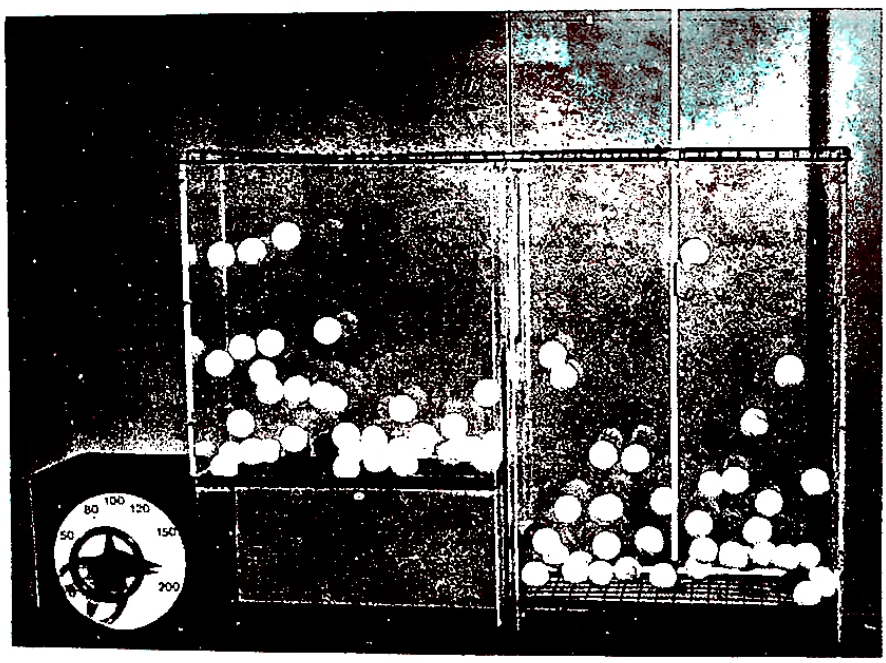


Figure 1 The reaction machine.

Molecules are represented by ping-pong balls which are supplied with 'energy' by a fan underneath the model. So, height represents energy. In use, in a reaction, each ball represents the whole reacting system (A *and* B-C in our general reaction).

The points illustrated with the model were:

1 the energy spread of molecules at a given temperature;

2 a reaction with a high energy barrier;

3 a reaction with a low energy barrier;

4 an exothermic reaction.

When showing 4, on which note the programme ended, the question was posed whether the level of the shelf in the 'product compartment' would affect the rate of the 'reaction'. The answer is given in a supplementary note below.

NOTE In the programme E_A is used as the symbol for the activation energy whereas the text uses the preferred symbol $E^{\ddagger}$.

Supplement to Television Notes for Unit 11

If the model correctly represents the effects of energy on a chemical reaction, the height of the 'product' compartment floor above or below the 'reactant' compartment floor represents the enthalpy change of the reaction and so does *not* affect the rate of the (forward) reaction.

TELEVISION UNIT 12

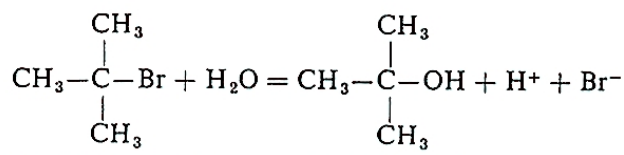
Pre-broadcast Notes

The programme

Subject
Following Chemical Reactions
Speakers
Professor M. J. Pentz
Dr R. A. Ross

This programme is about methods of following chemical reactions. In the main text of Unit 11 (up to the end of Section 11.4), the theoretical concepts used to discuss the rates and equilibria of chemical reactions have been developed. In Section 11.5 and in Unit 12 these concepts have been related to the things we can measure for chemical reactions – rates and equilibria. In your Home Experiments you have used one technique to determine rates and equilibria for two different reactions. This television programme will examine some other methods of following reactions.

You will see some equipment that you have met before – a glass electrode (TV9) and a polarimeter (TV 10). You will also see some new equipment – an *ebulliometer* and a *stop-flow* apparatus. You will have encountered the reactions used in the programme, or similar ones, in the main text or in your home experiments. One reaction performed is that between *tertiary*-butyl bromide and water. This reaction is very similar to the reaction between 1,chloropropane and the hydroxide ion which is used to illustrate various points in the text (Sections 11.3.1 and 11.3.2). The stoicheiometry, which you will be shown during the programme, is as follows:



tertiary-butyl bromide *tertiary*-butanol

Do not worry about the names of the chemicals. Just notice that this is a substitution reaction with hydroxide being substituted for bromide.

Post-broadcast Notes

Professor Pentz started the programme by referring to the atom and diatomic molecule reaction that had been dealt with in the television programme for Unit 11 and Dr Ross related the two mechanisms to rates. The mechanisms were

$$\begin{aligned} B - C &\xrightarrow{\text{Slow}} B\cdot + C\cdot \\ A\cdot + B\cdot &\xrightarrow{\text{Fast}} A - B \end{aligned} \qquad (1)$$

$$A\cdot + B - C \longrightarrow [A \cdots B \cdots C] \longrightarrow A - B + C\cdot \qquad (2)$$

The rate equations for the two mechanisms are different. The rate for mechanism (1) will be the rate of the slow step, which does not involve A, so,

$$\text{rate} = k_1[B - C]. \qquad (1)$$

In mechanism (2) the rate should depend on the concentration of both A and B – C,

$$\text{rate} = k_2[A\cdot][B - C]. \qquad (2)$$

So one way of distinguishing the two mechanisms is by determining whether or not the rate depends upon the concentration of A. The other pointer is the energy required for reaction (see text Sections 11.4 and 12.1).

The first reaction performed in the programme was that between magnesium and hydrochloric acid. The reaction was followed by collecting the hydrogen evolved:

$$Mg(s) + 2H^+(aq) = Mg^{2+}(aq) + H_2(g).$$

Can you think of any problems that might arise from using this procedure? (See comment A at the end of these notes.)

The next reaction performed was that between *tertiary*-butyl bromide and water. As Professor Pentz showed these liquids do not mix. It is not strictly true that no reaction can occur. The molecules can meet at the surface between the two liquids. Also your experience with solids (Unit 9) will suggest that some small amount of each liquid might dissolve in the other.

The two reagents were placed in a solvent that did not react with either. It was difficult to tell whether reaction had occurred or not. Dr Ross examined the expected stoichiometry:

$$CH_3{-}\underset{\displaystyle CH_3}{\overset{\displaystyle CH_3}{\overset{|}{\underset{|}{C}}}}{-}Br + H_2O = CH_3{-}\underset{\displaystyle CH_3}{\overset{\displaystyle CH_3}{\overset{|}{\underset{|}{C}}}}{-}OH + H^+ + Br^-$$

A test for $Br^-(aq)$, using silver ions, produced a white precipitate:

$$Ag^+(aq) + Br^-(aq) = AgBr(s).$$

Unfortunately, as Dr Ross stated, the presence of these reagents catalyses the reaction under investigation.

A glass electrode was then used to detect any change in the concentration of hydrogen ions and the response of the electrode was displayed on a chart recorder (Fig. 1).

Experimentally, it is found that the rate of the reaction does not depend on the concentration of water in the solution – only on the concentration of *tertiary*-butyl bromide. What does this suggest about the mechanism of the reaction? (See comment B at the end of these notes.)

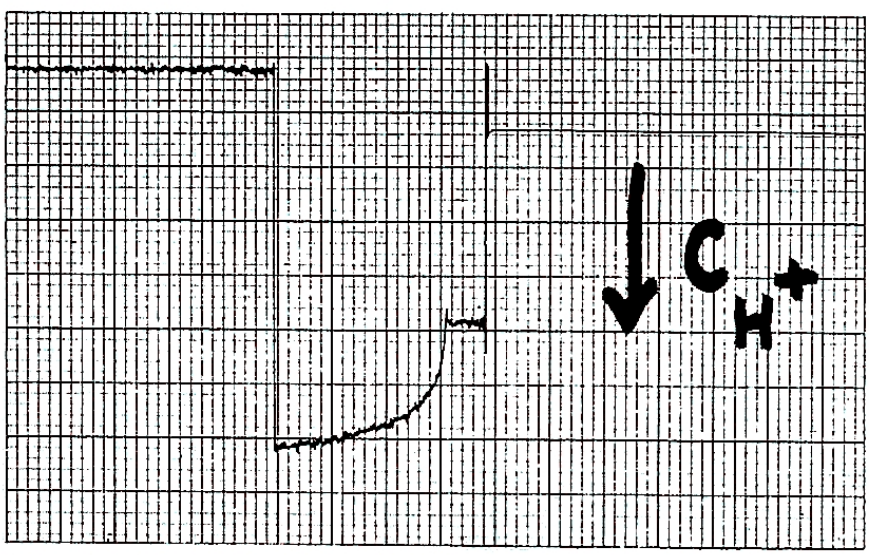


Figure 1 Glass electrode output. Photograph of the pen recorder trace obtained in the studio. Time is increasing to the left.

The possibility of following a reaction by detecting a change in an *overall* property of the reacting system was then discussed. One example of this type of procedure was demonstrated. The reaction was of the type:

$$A + B = AB$$

The reaction was followed by determining the boiling point of the solution containing the reactants. The apparatus used is called an *ebulliometer*. The apparatus is mainly a cell designed to boil a solution (Fig. 2). A condenser, a glass tube with cold water circulating in it, prevents solvent boiling away. Changes in the boiling point of the solution are determined with a thermistor. This is a device that responds to temperature and its response can be displayed as an electrical signal, a pen recorder being used. A typical reaction profile was obtained (Fig. 3). The increase in boiling point as each reagent (A and B) is added to the solution is followed by the fall in boiling point as the number of molecules in the solution decreases, that is, as the reaction proceeds.

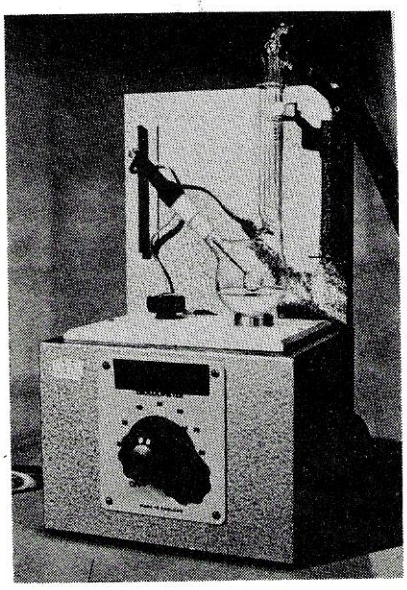


Figure 2 An ebulliometer.

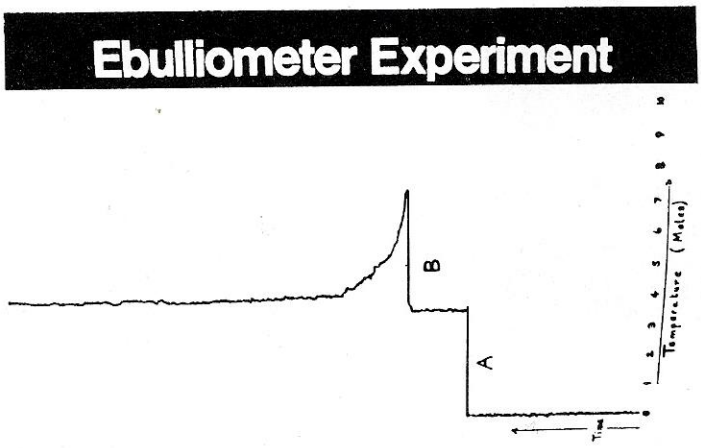


Figure 3 Pen recorder trace from the ebulliometer.

The next technique demonstrated was the polarimeter, which you first saw in the television programme for Unit 10. The point made in this

programme was that the angle of rotation of polarized light depends on the concentration of optically active substance present. The implication is that if a reaction consumes an optically active molecule, the decrease in rotation would be a measure of the progress of the reaction.

The last reaction demonstrated was the one that you have used in your Home Experiment for this Unit:

$$Fe^{3+} + SCN^{-} = FeSCN^{2+}.$$

You have seen how rapidly this reaction occurs. In the programme, this reaction was followed in much the same way that you followed it. The absorption of green light by the ferrithiocyanate ions was detected. An oscilloscope was used to determine the short reaction times involved. You have seen this instrument used for this purpose in a number of earlier programmes. A diagrammatic representation of the stop-flow apparatus is shown in Figure 4 and the trace obtained in Figure 5. You will see the similarity of Figure 5 to the results you obtained in your Home Experiment

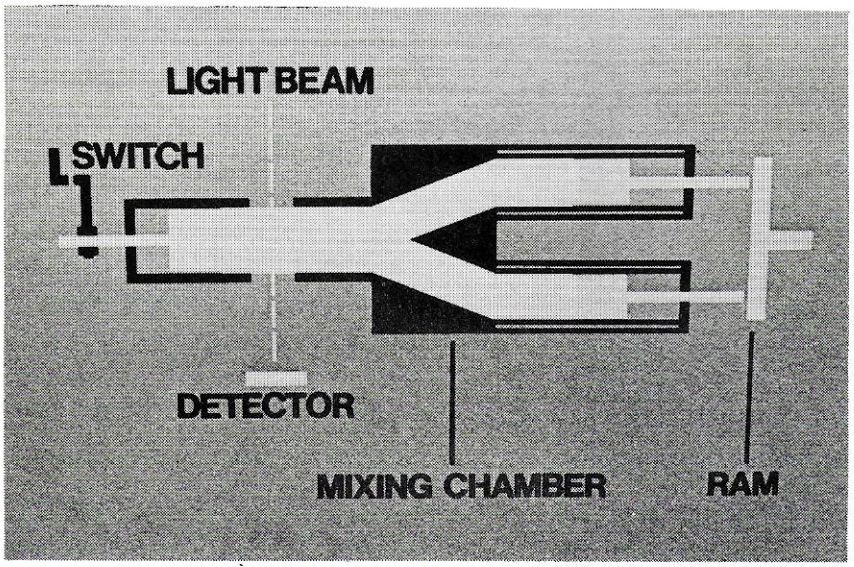


Figure 4 Stop-flow apparatus (diagrammatic).

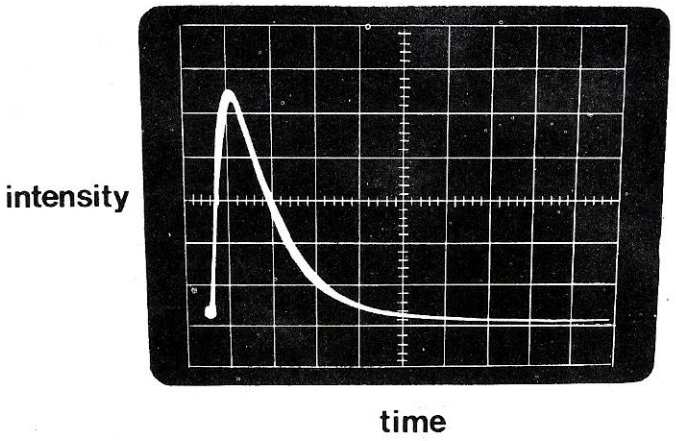


Figure 5 Oscilloscope trace from stop-flow apparatus.

for Unit 11. The intensity of light transmitted by the solution falls as the concentration of the absorbing species (a product) increases. As with your Home Experiment, a concentration versus time graph would 'mirror' Figure 5.

The initial peak in Figure 5 is caused by the plunger removing completely reacted solution (from the previous run) from the light path. This is then immediately replaced by solution initially containing no product (so the intensity of transmitted light is at its maximum value).

The methods demonstrated in this programme could all be classified

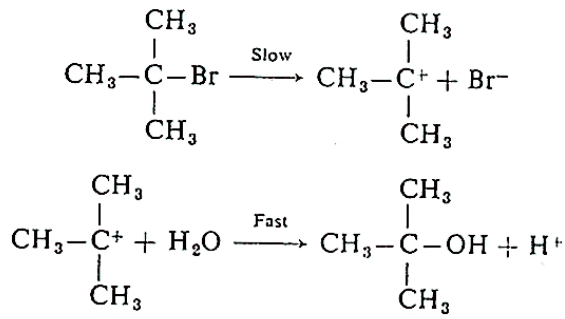
as physical methods. These have the advantage that the reaction can be followed continuously. These methods can be contrasted with chemical methods, where the concentration at a given time of one of the reagents is determined by chemical analysis.

Comment A

At least one problem would be that the pressure on the gas being collected changes as the water level falls. This would have to be allowed for. Another problem would be that the magnesium tends to float as soon as any reaction occurs and hydrogen collects on its surface. Lack of reproducibility of this surface would also cause problems.

Comment B

This suggests that the mechanism for the reaction is akin to mechanism (1) at the beginning of these notes. The accepted mechanism is:



TELEVISION UNIT 13

Subjects
Polymerization; Structure Property Relationships in Polymers
Speakers
Professor M. J. Pentz
Professor L. J. Haynes
Dr R. R. Hill

Pre-broadcast Notes

We make two polymers, and illustrate graphically how their mode of formation from monomer molecules classifies the one as being an addition polymer and the other a condensation polymer. You will see four polymers in all and we will be attempting to explain some of the differences in their properties using analogies with models. Finally, we go outside the studio and into the factory. There we see how materials like the ones we made in the test tube and beaker are turned into the more familiar plastic consumer goods.

You should read Sections 13.1 and 13.2 of the text before viewing the broadcast.

Post-broadcast Notes

The formation of an addition polymer usually requires the presence of a double bond, especially C=C, in the monomer molecule. There are several means by which polymerization can be initiated; a common one involves reaction of monomer molecules with free-radicals (RO· for example). No molecular fragments are lost and an addition polymer has essentially the same molecular formula as the monomer from which it was made. Polymerization ceases when two free radicals combine. Usually these are two growing chains, though in the programme we show a reaction between a growing chain and an initiator free radical for simplicity.

Condensation polymerization can occur with molecules of the same type – provided they have two different reactive groups, as occur in the amino acids ($NH_2-R-COOH$) It can also occur between molecules of different types both of which contain two similar reactive groups, e.g. NH_2-R-NH_2 and $HOOC-R'-COOH$. Condensation polymerization does not require weak double bonds or a catalyst, but it does

require at least two reactive 'linking groups on each molecule. A molecular fragment is always lost when a polymer link is formed,

e.g. $HOOC-R'-COOH + H_2N-R-NH_2 \rightarrow$

$HOOC-R'-CO-NH-R-NH_2 + H_2O.$

The physical properties of a polymer are largely determined by the structure of its chain-like molecules. In the programme the formation of nylon was shown (Fig. 1). Fibres formed from nylon have great tensile strength because the long polymer chains are held in bundles by strong attractive forces (see in text under 2.2.A, Fibres).

It is possible for polymers of the same compound to have different properties. This was shown by the two samples of polypropylene, one of which was very hard and strong, and the other a sticky mass. This again can be explained by the ability of the polymer chains to align alongside one another. The structure of the sticky material, shown in Figure 2, is irregular. The structure of the strong polymer is the regular structure shown in Figure 3. Although these photographs are useful in demonstrating the difference between the two structures, they do not represent the true molecular shape of either form of polypropylene. In fact, in both cases, the chain twists to a conformation in which the relatively bulky CH_3 groups (the grey spheres) are as far away from each other as possible.

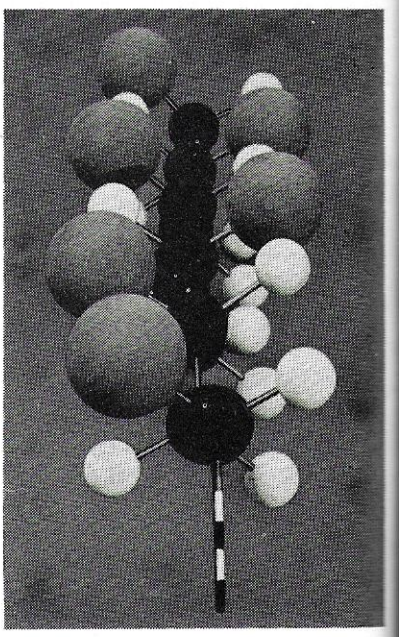


Figure 2 The irregular form of polypropylene.

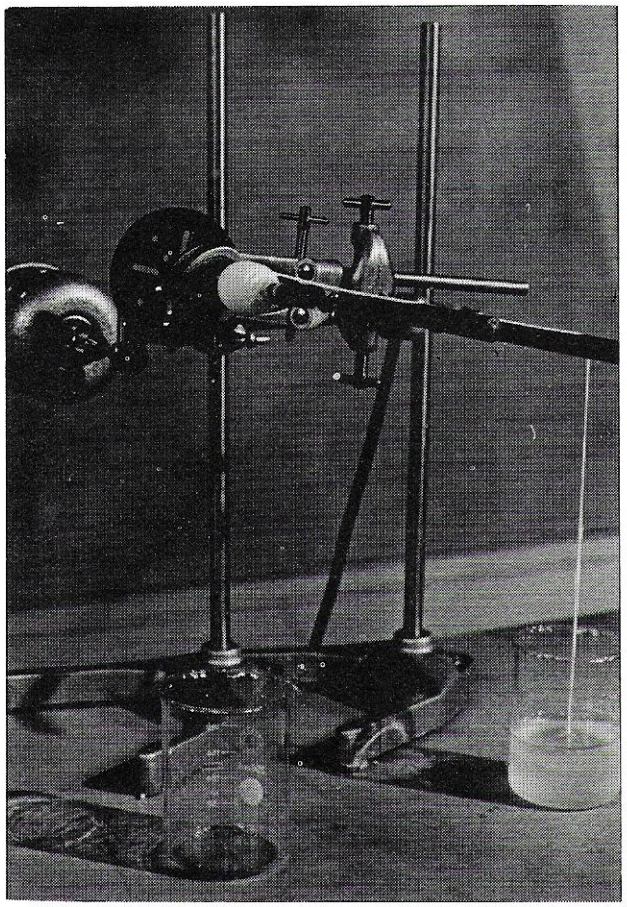


Figure 1 The nylon rope experiment.

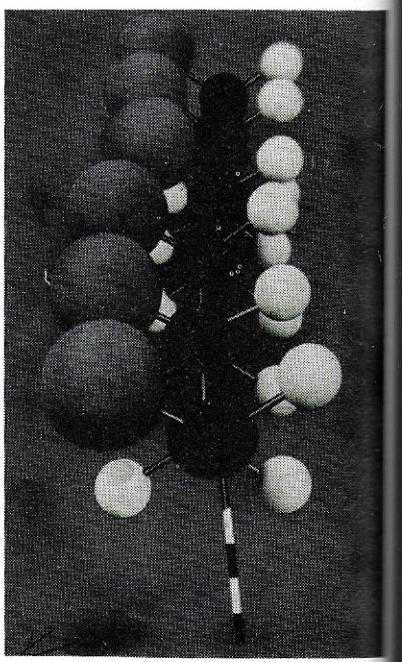


Figure 3 The regular form of polypropylene.

In the case of the irregular structure, this results in a crazy tangle so that it is impossible for the chains to align and pack closely together. However, while the regular structure also twists to give the maximum separation between CH_3 groups, its very regularity leads to conformations which are essentially helical, much like a long, open coiled spring. These 'helices' are basically straight, so that the chains can align and close packing is made easier by a degree of overlapping that the helix form allows.

TELEVISION UNIT 14

Subject
The Chemistry and Structure of the Cell
Speakers
Professor Steven Rose
Professor M. J. Pentz
Mr S. W. Hurry

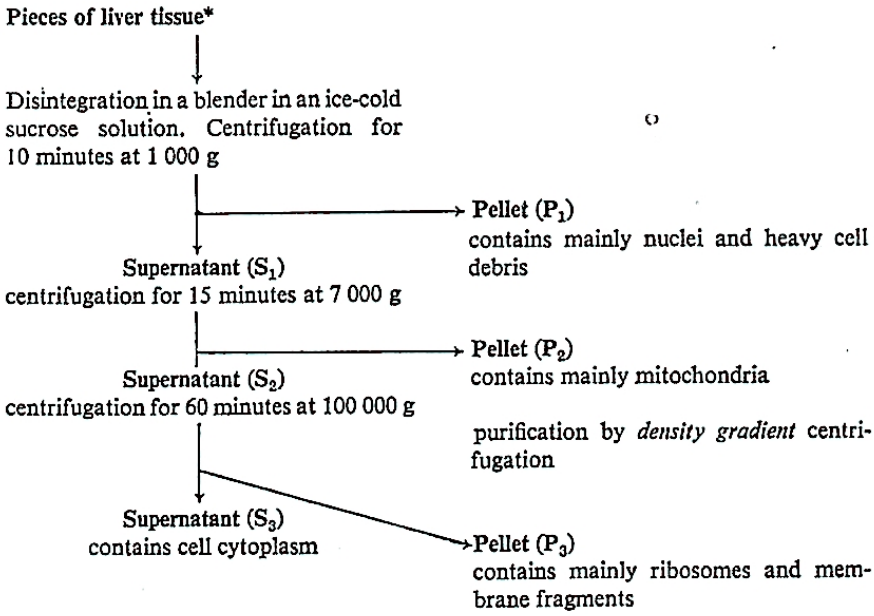
The programme is divided into two parts. The first deals with the structure of cells and with one technique used to find out the three-dimensional shape of cells and their parts. In the second part, liver tissue is broken up and the organelles of liver cells are separated from each other. This involves centrifuging, first at low speeds, then recentrifuging at much higher speeds, finally using a density gradient technique.

Pre-broadcast Notes

Before the broadcast you should have studied Section 14.5.1 in the Main Text of Unit 14 and be familiar with the general structure of animal cells. You should also know the meanings of the terms: cell membrane; cytoplasm; endoplasmic reticulum; nucleus; and mitochondrion. You should have carried out the investigation described in Section 14.3.2 for yourself, and should also have read Section 14.6, so as to be familiar with the principles of centrifugation.

Post-broadcast Notes

The procedure for isolating cell organelles, as described in the broadcast, is outlined in diagrammatic form below.


Pieces of liver tissue*
Disintegration in a blender in an ice-cold sucrose solution. Centrifugation for 10 minutes at 1 000 g
Pellet (P_1)
contains mainly nuclei and heavy cell debris
Supernatant (S_1)
centrifugation for 15 minutes at 7 000 g
Pellet (P_2)
contains mainly mitochondria
Supernatant (S_2)
centrifugation for 60 minutes at 100 000 g
purification by *density gradient* centrifugation
Supernatant (S_3)
contains cell cytoplasm
Pellet (P_3)
contains mainly ribosomes and membrane fragments

* See also the TV programme of Unit 16 for further separation of *lysosomes*.

The method, though typical, can be varied in many ways, depending for example on the tissue being examined, the organelle being studied and the purpose for which the organelle is required. The operations shown in the programme are rather crude and simple.

After watching the programme you should:
1 understand better how knowledge of the structure and shape of cells and their organelles is gained; 2 be confident of your ability to make slides of cells and examine them with the McArthur microscope; 3 have understood the problems posed by artefacts in interpreting work with the microscope; 4 feel that you could use a simple centrifuge.

TELEVISION UNIT 15

Subject
Cell Dynamics 1
Speakers
Professor M. J. Pentz
Mr S. W. Hurry
Professor S. Rose

Pre-broadcast Notes

The first part of the programme is concerned with the salivary amylase experiment which is the Home Experiment for this Unit. The techniques involved are demonstrated by Stephen Hurry. The setting up of the colorimeter, making the standard solutions and using the standard curve are all shown.

The second part of the programme is a biochemical experiment by Steven Rose.

Post-broadcast Notes

In the biochemical experiment, the metabolism of glucose by isolated slices of rat liver was followed (the principle of the use of such tissue slices is discussed in *The Chemistry of Life*, mid-page 107 to the end of page 108, which you should read now). The tissue slices were placed into a solution of appropriate composition containing glucose, and incubated in the presence of oxygen.

Three different measurements, each depending on a different technique, were made:

1 the consumption of oxygen by the tissue over 1 hour;

2 the production of carbon dioxide by the tissue over 1 hour;

3 the production of lactic acid by the tissue over 1 hour.

All three measurements were made in the same experiment using the same set of tissue slices.

1 *To measure the oxygen consumption* The incubation is carried out in sealed flasks, which are connected to manometers (which register changes in gas pressure) developed by Otto Warburg and named after him (see Unit 15 Radio Notes). The flasks are incubated at exactly 37°C, and are kept shaking during the incubation to ensure efficient exchange of gas across the surface of the tissue. During the incubation, carbon dioxide may be given off. To trap this carbon dioxide, both to prevent it from affecting the manometer reading and to enable the amount present to be measured later, a separate compartment of the flask contains a piece of filter-paper moistened with the alkali sodium hydroxide, which dissolves the carbon dioxide.

The flask and manometer system is shown in Figure 1.

The manometer has two arms, the right-hand one connected to the incubation flask, the left-hand one open to the atmosphere. It is the right-hand arm which, together with the flask, forms a sealed system. If gas is taken up by the tissue in the flask, the fluid in the right-hand manometer arm will rise, so as to equalize the pressure in the system. The manometer arms are graduated, and the height of fluid in them can be adjusted by a screw device. If the level in the right-hand arm is kept adjusted to a particular mark (the 15.0 cm calibration in the incubation you will see), then the sealed arm is always kept at constant volume. The change in the height of the fluid in the left-hand, open arm can then be measured, and is proportional to the amount of gas taken up by the tissue in the right-hand arm.

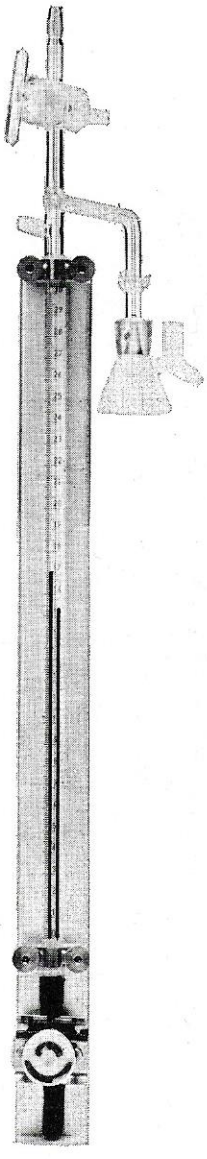


Figure 1

In Figures 2 a and b the height of the fluid in the manometer arms at two successive readings, 10 minutes apart, is shown. In both, the fluid in the right-hand arm has been adjusted to 15.0 cm. In 2a the fluid in the left-hand arm is at a height of 16.7 cm and in 2b, 10 minutes later, it is 15.3 cm. The difference between the two readings is 1.4 cm and, if the volume of the flask and a number of other constants are known, this figure can be used to calculate directly the amount of oxgyen (in micromoles) taken up by the tissue.

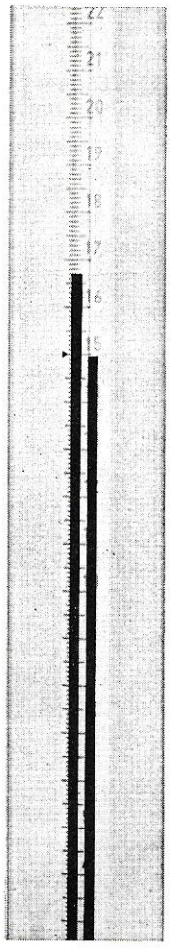


Figure 2a

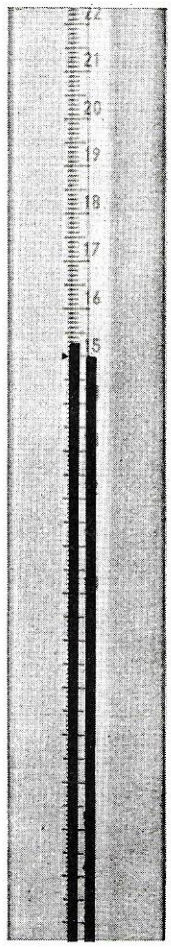


Figure 2b

2 *Carbon dioxide production* The carbon dioxide given off during the incubation is absorbed on alkali-moistened filter paper. There are analytical chemical techniques to measure carbon dioxide, but these are time-consuming and often inaccurate for the small amounts involved. Instead, we use a better method involving radio-isotopes. If the glucose we add as substrate for the incubation is radioactively labelled (that is, a proportion of the normal ^{12}C atoms in the glucose are replaced by ^{14}C), then the carbon dioxide generated from the glucose will also be radioactively labelled:

$$^{14}C_6H_{12}O_6 \longrightarrow 6^{14}CO_2 + 6H_2O$$

The filter paper contains radioactively labelled carbon dioxide at the end of the incubation. The amount of radioactivity present will be proportional to the amount of carbon dioxide. Thus, a measurement of the amount of radioactivity present on the filter paper will indicate how much carbon dioxide has been produced. We can determine the radioactivity present in the filter paper with a device known as a scintillation counter, and we will show you this on the TV programme. This device provides a measure of the amount of radioactive emission from a sample in a given time: that is, disintegrations/minute which can be assumed to be proportional to CO_2 produced.

3 *Lactic acid production* We cannot trap the lactic acid produced during the incubation in the same way as the carbon dioxide. At the end of the incubation, it will still be present in the tissue slice and the surrounding fluid. It too will be radioactively labelled; but there are many other radioactively labelled substances present in the slice and fluid, including, of course, unchanged glucose. So merely measuring the radioactivity will not do, unless we were to extract and purify the lactic acid first, which would be possible, for instance, by chromatography. But there is a more direct method we can use. We can estimate the lactic acid *enzymically*. You are already familiar, from the Main Text, with the reactions which will enable us to do this (Section 15.5.2).

Consider the reversible reaction which converts lactic and pyruvic acid (equation 3 of Section 15.5.4 of the Unit – written the other way around this time).

$$\underset{\textit{lactic acid}}{CH_3CHOH.COOH} + NAD \underset{\textit{lactic dehydrogenase}}{\rightleftharpoons} \underset{\textit{pyruvic acid}}{CH_3.CO.COOH} + NADH_2$$

In the presence of lactic dehydrogenase and NAD, all the lactic acid in the tissue will be converted to pyruvic acid. That does not help much,

for we do not have a way of measuring pyruvic acid! But during the same reaction, the NAD is converted into $NADH_2$, and it happens that there is a very convenient way of measuring this. In the visible range, both NAD and $NADH_2$ are colourless; but in the ultraviolet, there is a difference between them. Figure 3 shows that $NADH_2$, but not NAD, absorbs at a wavelength of 366 nm. We can thus use an assay equivalent to the colorimetric procedure of your own enzyme assays with amylase, to measure the *change* in absorbance at 366 nm in a reaction tube to

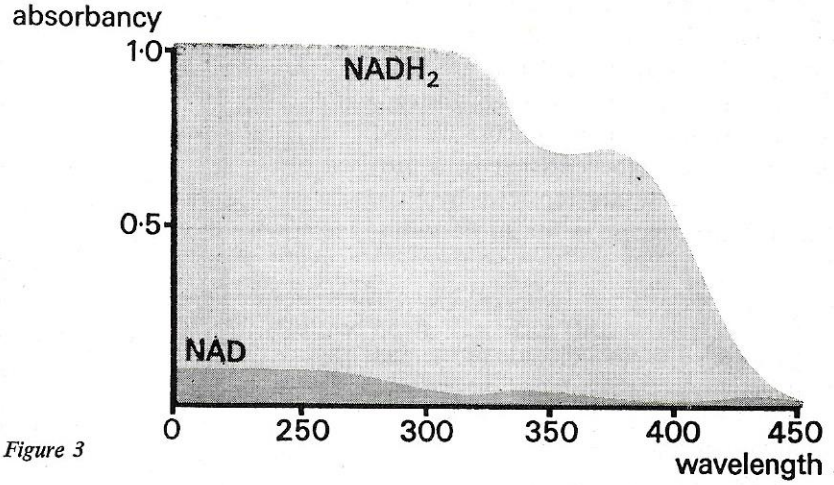


Figure 3

which our sample of tissue extract containing lactic acid, NAD, and a small amount of the enzyme lactic dehydrogenase have been added. The change in absorbance as the reaction proceeds is then a measure of the amount of lactic acid in the sample.

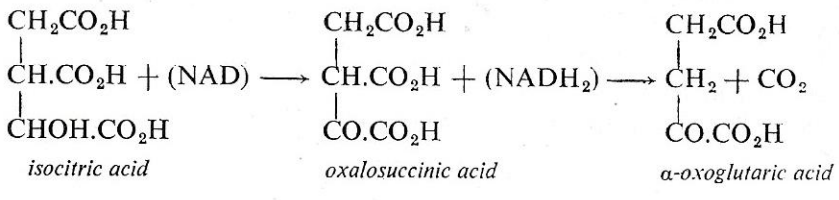
TELEVISION UNIT 16

Pre-broadcast Notes

Subject
Cell Dynamics II
Speakers
Professor M. J. Pentz
Professor Steven Rose
Professor Christian de Duve

This programme has as its theme, control and regulation in the cell. Two types of regulation are discussed: that achieved by the modification of rate-limiting reactions; and that gained from structural barriers within the cell.

To demonstrate the first type of control, one of the reactions of the Krebs cycle is studied. The reaction is a complex one in which the enzyme isocitric dehydrogenase converts isocitric acid to α-oxoglutaric acid. The sequence of reactions is shown in Figure 13, p. 131 of *The Chemistry of Life*, in equation 18 of p. 133, and is reproduced here:



During this reaction, NAD is converted to $NADH_2$. The rate of reaction can therefore be measured spectrophotomètrically by examining the change in absorption at 366 nm, exactly as the activity of lactic dehydrogenase was measured last week. In this experiment, the slope of the trace made by the pen-recorder is proportional to the activity of the enzyme isocitric dehydrogenase.

The enzyme is prepared by making an extract of yeast. The cells of the spectrophotometer are already set up, with the substrate, isocitric acid, the enzyme isocitric dehydrogenase, and the buffer present.
Professor Rose starts the enzyme reaction by the addition of NAD to the cells, and records the change in absorbence registered in the spectrophotometer.

The enzyme isocitric dehydrogenase is one of the slowest of the Krebs cycle enzymes, and therefore *rate-limiting* for the reaction sequence. By the argument of the text of the Unit, and *The Chemistry of Life*, pp. 187–91, we should therefore expect to find its rate affected by a variety of products of the reaction sequence. In the TV demonstration, the effects of two substances, ATP and AMP, on the rate of the reaction are shown. Neither of these substances is directly involved in the reactions of the enzyme: ATP is an end product, many stages away along the reaction sequence; while AMP is itself one of the products of ATP breakdown (see Fig. 22, p. 192, of *The Chemistry of Life*). Yet, in the reactions shown, ATP and AMP can be seen to have very striking effects on the rate of the isocitric dehydrogenase reaction. You ought to be in a position, from reading the text of the Unit and *The Chemistry of Life*, to predict the effects of adding ATP and AMP on the rate of the reaction.

> Write down your predictions before watching the broadcast, so that you can check them during the demonstrations.

The end-product effects shown in these examples are cases of the *allosteric control* of enzyme activity referred to in the second paragraph of p. 98 of *The Chemistry of Life*.

You are expected to remember the principle that these experiments illustrate, but not the details of the reactions themselves.
In the second part of the programme, *control by structure* is exemplified in terms of a detailed discussion of the properties of a particular subcellular organelle, the lysosome. The discoverer of the lysosome, Professor Christian de Duve, of the University of Louvain, Belgium, describes how he isolated the particle. The ways in which the structure of this organelle can be utilized to maintain the cell in health, and in which lysosomal malfunction can be a cause of disease, are described, with particular reference to one disease, that of *silicosis*. The importance of the lysosomal membrane in controlling the enzymes present within it is emphasized.
You should remember both general principles of cellular control mechanisms:

1 control by the regulation of rate-limiting reactions;

and

2 structural control,

and be able to illustrate their importance for the functioning of normal cells.

TELEVISION UNIT 17

Pre-broadcast Notes

Subjects
1 Mitosis
2 Transformation

Speakers
Professor M.J. Pentz
Stephen W. Hurry
Dr Brian S. Cox

The first section of the programme is based on a film of cells dividing. In the second part, one of the important investigations in the development of modern genetics is considered.

Stephen Hurry will describe mitosis in living cells, first of all in the arbitrary stages that may be recognized and then as a continuous process. The demonstration of mitosis is intended to complete your exercise of interpreting the photographs of mitosis in the crocus that you have been provided with. So it is essential that before you view the programme you read at least Sections 17.1, 17.12 and 17.15 of the Main Text and attempt the interpretation exercise based on the pictures of the dividing crocus cells (Questions 13–25).

In the film, the cells in which the division process is analysed are taken from the seeds of the African Blood Lily. These are cultured in conditions which enable them to divide normally while being filmed. One particular cell is photographed during one complete cycle of mitosis.

But mitosis is a slow process; it may take several hours. To telescope the events of mitosis into a shorter more practical time, time-lapse photography is used. To make mitosis visible, because in living cells nuclei and chromosomes are almost transparent, the preparation is examined and filmed using a special microscopical technique called phase contrast. The chromosomes appear dark in colour against the more transparent background of the rest of the cell. Stains generally cannot be used to show up living chromosomes because they react chemically with cellular components and may then alter the behaviour of the cell—the purpose of the exercise, to observe normal mitosis in living cells, would then be lost.

During the first part of the programme the whole sequence of the division cycle is broken down into a series of arbitrary stages. Each of these stages has been given a name and each stage can be characterized by particular events. The stages and their characteristic features are:

Interphase	Nucleoli are prominent in the nucleus, but no other structures are visible. Yet duplication of DNA is taking place.
Prophase	The chromosomes become apparent and the nuclear membrane bursts, setting the chromosomes free in the cell. Nucleoli vanish.
Metaphase	The chromosomes unravel and become shorter and thicker, moving into the centre of the cell. The centromeres divide.
Anaphase	The chromosomes separate and move towards the ends of the cell.
Telophase	Chromosomes lose their structure and a new nuclear membrane reforms around each daughter nucleus. A 'cell wall'* develops separating the daughter cells from each other.

**'Cell wall' is used here and in the broadcast, although in fact the structure is not the same as the cell wall around the cell at this stage. But you need not be concerned with this complexity now.*

Do not attempt to memorize these names—the stages are arbitrary; it is much more important to think of this type of division, mitosis, as a means by which the replicated DNA is distributed equally to the two daughter cells so that each is genetically identical with the parent cell.

The second part of the programme is presented by Dr Brian Cox of the Botany School, Oxford University.

The transformation experiment re-creates one of the crucial experiments which proves to you that DNA *really* is the genetic material. Dr Cox demonstrates this by adding genetic material (DNA) from one strain of a bacterium to another, so that a genetically determined characteristic of the former is transferred to the latter. The latter strain is 'transformed'. Key steps in the experiment are shown and fit into the flow chart for the experiment, shown in Figure 1.

The demonstration also has another purpose. Dr Cox shows you some of the apparatus, sterile techniques, precautions and experimental methodology that the microbiologist uses to perform this experiment in particular. The same approach applies to microbiological work in general. The transformation shown in the programme actually takes a few days to complete. We are able to show various stages in the complete sequence. The crux of the experiment is that if these plus/minus differences in the bacteria are due to different DNAs, then it may be possible to add extracted 'plus' strain DNA to 'minus' strain bacteria and transform the 'minus' strain into a 'plus' strain. The DNA is prepared from the 'plus' strain by culturing a great number of the 'plus' cells in a nutrient solution, and then the cells are broken open.

You can follow the procedure during the broadcast by reference to Figure 1.

Post-broadcast Notes

The Transformation of bacterial cells

Stage 1

The two strains of the bacterium are grown in a liquid growth medium. This growth medium supplies everything the organisms need for healthy growth: an energy source, simple salts and the amino acids that the bacteria cannot make for themselves.

The strain marked + can make the amino acid tryptophan, one of the amino acids necessary for growth, from simpler raw materials present in the growth medium.

The strain marked — cannot make tryptophan, because it lacks one of the enzymes of the metabolic pathway leading to tryptophan production. So growth will only take place if tryptophan is supplied in its growth medium.

Stage 2

To show the effect of tryptophan on growth, small samples of each strain are spread out, side by side, on two plates of growth medium, one of which lacks tryptophan (marked —), while the other (marked +) contains tryptophan. The results of growth can be seen as a white zigzag mark – due to a large number of bacterial colonies. In this case, the growth medium is turned into a solid jelly by adding a gelling agent which has no food value by itself. The bacteria cannot move about; so they grow and divide where they have been smeared on the jelly surface--eventually having divided enough times, forming visible colonies.

Figure 1 Flow chart of the experiment on the transformation of bacterial cells.

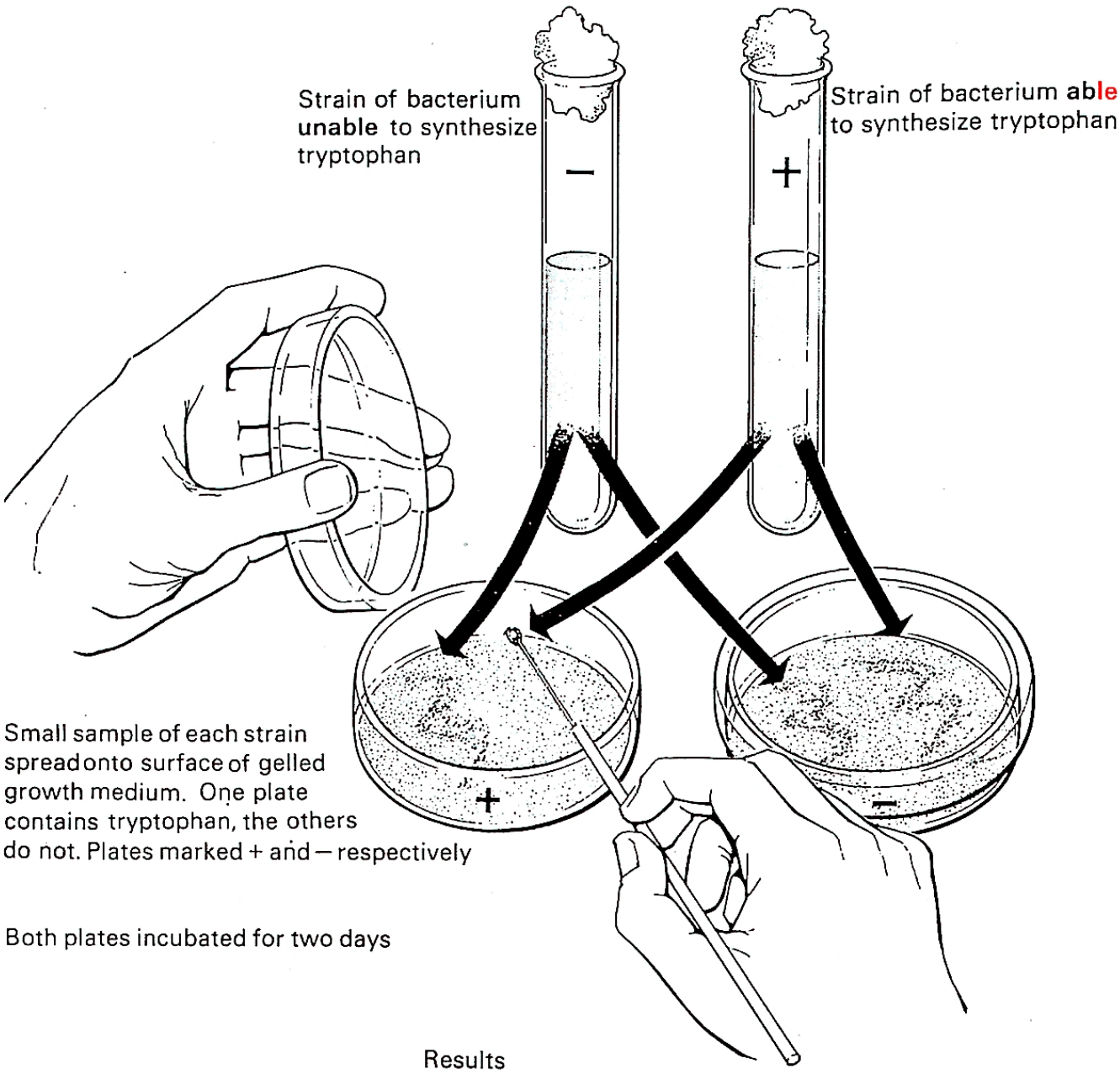
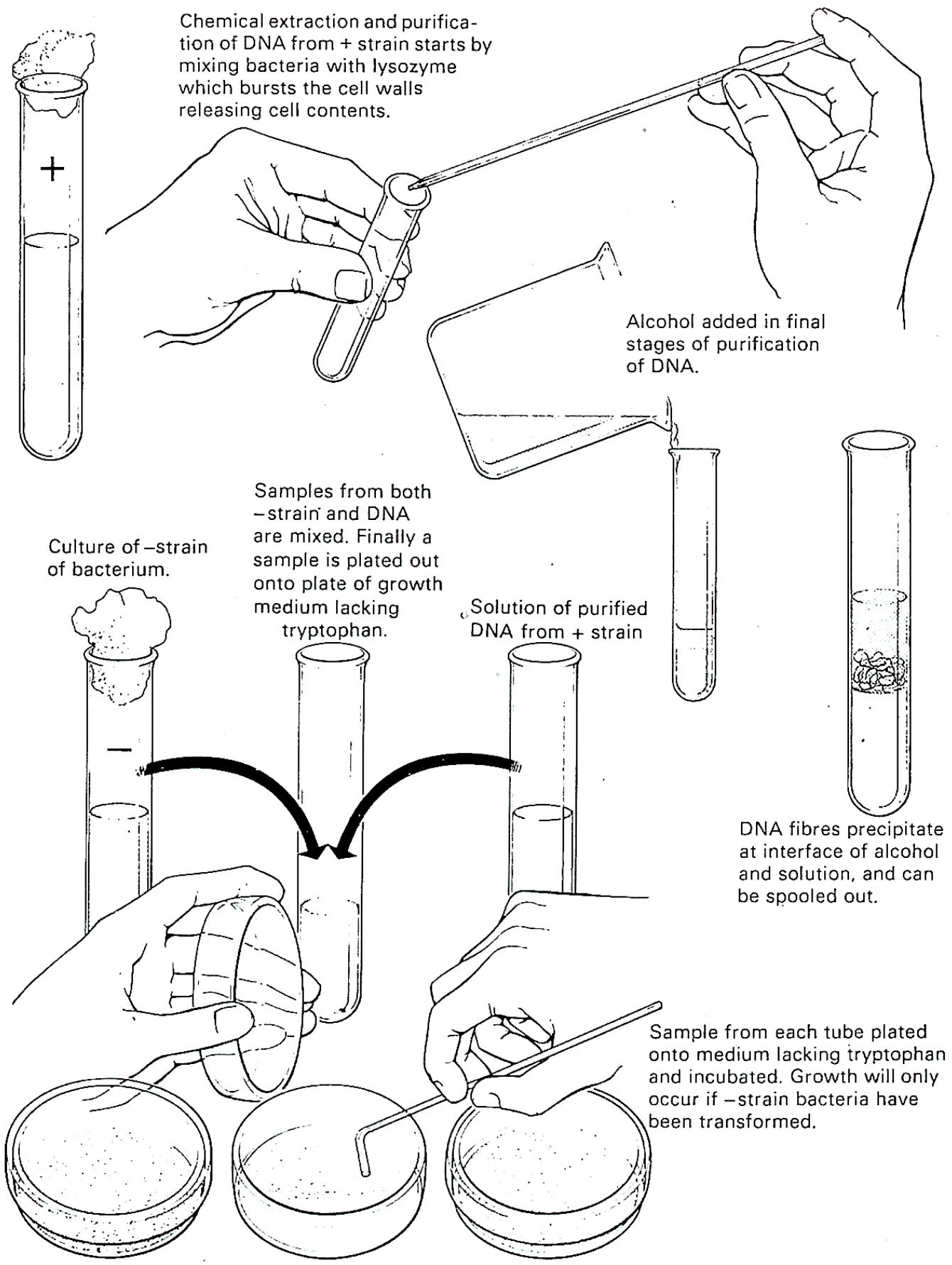

Strain of bacterium **unable** to synthesize tryptophan
Strain of bacterium **able** to synthesize tryptophan
−
+
Small sample of each strain spread onto surface of gelled growth medium. One plate contains tryptophan, the others do not. Plates marked + and − respectively
Both plates incubated for two days
Results
+ ve plate
− ve plate
+
−
Plate **with** tryptophan in growth medium — both strains grow.
Plate **without** tryptophan in growth medium — only + strain grows

Figure 1 (cont.)


Chemical extraction and purification of DNA from + strain starts by mixing bacteria with lysozyme which bursts the cell walls releasing cell contents.
+
Alcohol added in final stages of purification of DNA.
Culture of –strain of bacterium.
Samples from both –strain and DNA are mixed. Finally a sample is plated out onto plate of growth medium lacking tryptophan.
Solution of purified DNA from + strain
–
DNA fibres precipitate at interface of alcohol and solution, and can be spooled out.
Sample from each tube plated onto medium lacking tryptophan and incubated. Growth will only occur if –strain bacteria have been transformed.

Stage 3

IF . . . the difference between the two strains of bacterium is due to a difference in their DNA

THEN . . . DNA extracted from the + strain can be added to —strain bacteria

and IF . . . any of these take up either whole DNA molecules or even that part of the DNA which contains the appropriate genetic instructions

and IF . . . this absorbed DNA can be translated THEN . . . the — strain cells ought to behave as + cells and so be able to make its tryptophan, and so grow on a tryptophan-less medium where before cells like it could not.

Stage 4

Extraction and purification of DNA from the + strain is done in this case by adding an enzyme, lysozyme, which digests the cell wall of the bacterial cell, setting free the cell contents. Bacteria have no nuclear membranes, so the DNA is free in the resulting 'soup' of broken cells. By fairly simple chemical treatment, the DNA can be extracted—the last stage of extraction is shown. This involves precipitating the DNA by adding alcohol to the solution. DNA fibres appear at the alcohol/'soup' interface and can be removed by spooling them on to a glass rod.

Stage 5

The spooled DNA fibres are redissolved in a sterile salt solution. Then some of the DNA-containing solution is mixed with a sample of the — strain of the bacterium. This mixture is incubated for a few hours to allow absorption of the DNA into the bacterial cells.

Stage 6

A sample of the incubated mixture is removed and spread out on solid growth medium which lacks tryptophan. The spreader used in this case differs from that used in Stage 1 because the sample to be examined is bigger. The sample must be bigger, because experience has shown that transformation is a rare event and so a large number of bacterial cells must be examined in order to find any that have been transformed. As the bacteria are in the liquid mixture, a largish sample of the liquid culture must be used.

Note: transformation is detected by the ability of the originally — cells (tryptophan requiring) to grow on a growth medium lacking tryptophan. Growth itself is detected by the presence of 'white' circular colonies of bacteria on the plate. Each colony is made up of millions of minute individual bacteria, all the offspring of a single transformed cell.

You were asked to think (as part of the methodology) about the use of control experiments to support any conclusions. It was necessary to do two control experiments, to check that the untreated — strain would not grow on the tryptophan-lacking medium nor on the + DNA extract.

The fact that transformation is a permanent inheritable genetic change can be shown (although this step is not made in the programme) by isolating a single bacterium from a transformed colony and culturing it on its own. Its descendants can then be examined to see if they require tryptophan or if they can synthesize it. The results show that they can synthesize tryptophan and so the transformation must be inherited. Similarly other chemicals isolated from the cells can be tested for their transforming ability. Exhaustive tests show that *only DNA* is capable of bringing about transformation.

As a result of transformation experiments, attention was concentrated on DNA and its role as the chemical basis of inheritance. From these studies, and others which followed, grew the confidence that the genetic material was DNA, culminating in the decoding of the genetic code and the understanding of the material basis of life.

TELEVISION UNIT 18

Pre-broadcast Notes

The television programme falls into two halves. The *first half* shows you a variety of microscopic living organisms that are composed of only a single cell. In the *second half,* we show you a demonstration that is carried out for students in conventional universities so that you have the opportunity to share a similar experience. We concentrate on a single organ in a multicellular organism—the rabbit's heart. The overall aim of the programme is to illustrate some of the problems of life as faced by organisms of very different sizes.

Subjects
1 Single Celled Organisms
2 Control of an Organ

Speakers
Professor M. J. Pentz
Dr M. E. Varley
Dr R. M. Holmes

Text

Read through these notes and make sure that you have read the following Sections of the text of the Unit– 18.1; 18.1.1; 18.3.2 to 18.3.4; 18.4.2.

Post-broadcast Notes

The microscopic single celled organisms shown in the first half of the programme are called the 'Protista'. Dr Varley uses models (Fig. 1) to demonstrate the basic structure of three common protistans–*Paramecium, Euglena* and *Amoeba*–and the organisms are shown alive in the film.

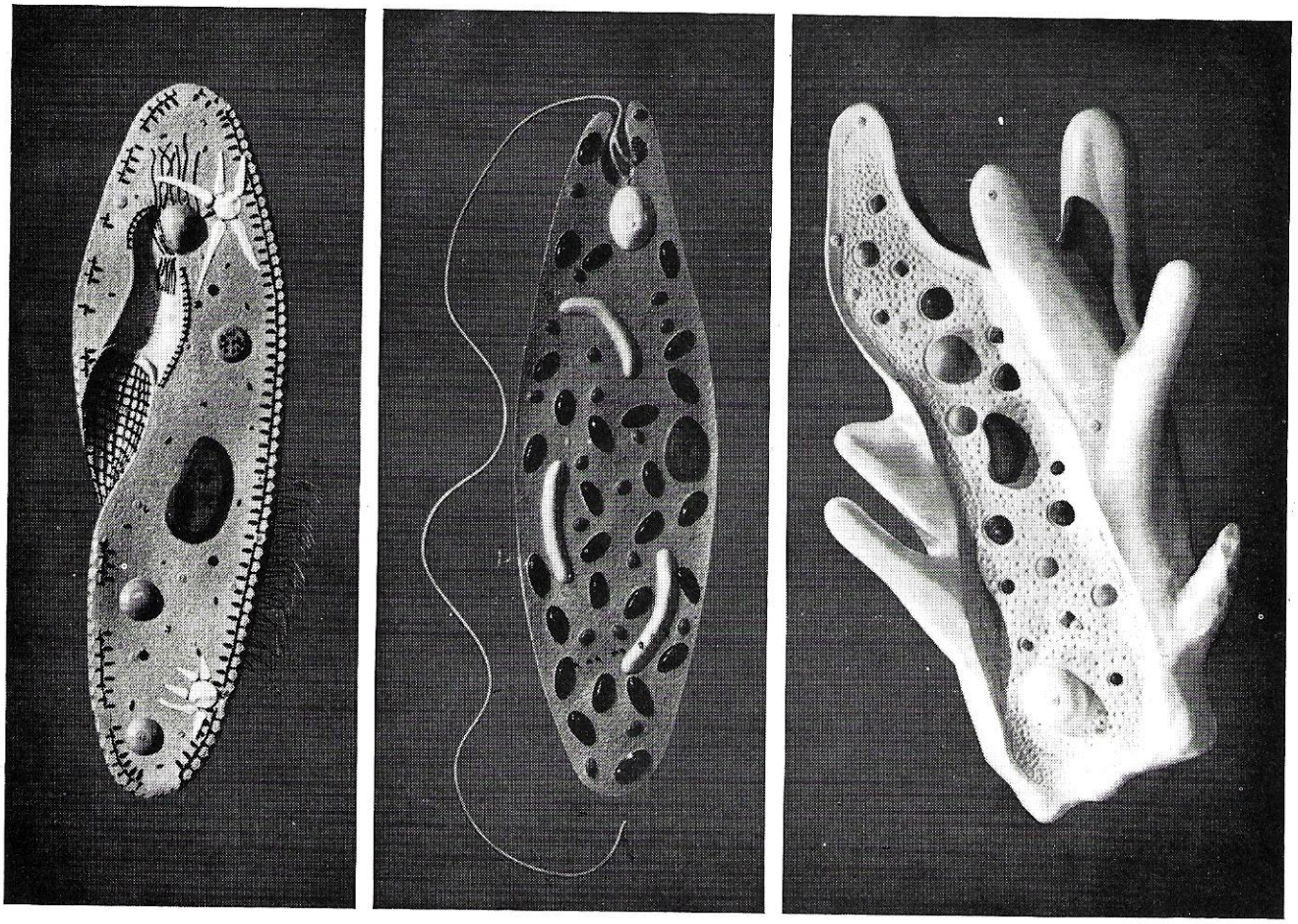


Figure 1 Paramecium *Euglena* *Amoeba*

The vital activities of feeding and movement, are illustrated in many different protistans, showing something of the wide variety of habits possible with the organelles present in single cells. Organelles pumping water out of cells (contractile vacuoles) are seen in action and we illustrate many different ways in which cilia can be arranged and the different functions performed.

In the second half of the programme we show you a demonstration that is carried out on the rabbit's heart. This is similar to the human heart described in the text and we show you how it can be kept beating outside the body and how it responds to two substances that are released by the autonomic nervous system. We record the responses as kymograph (smoked drum) records similar to those in the text.

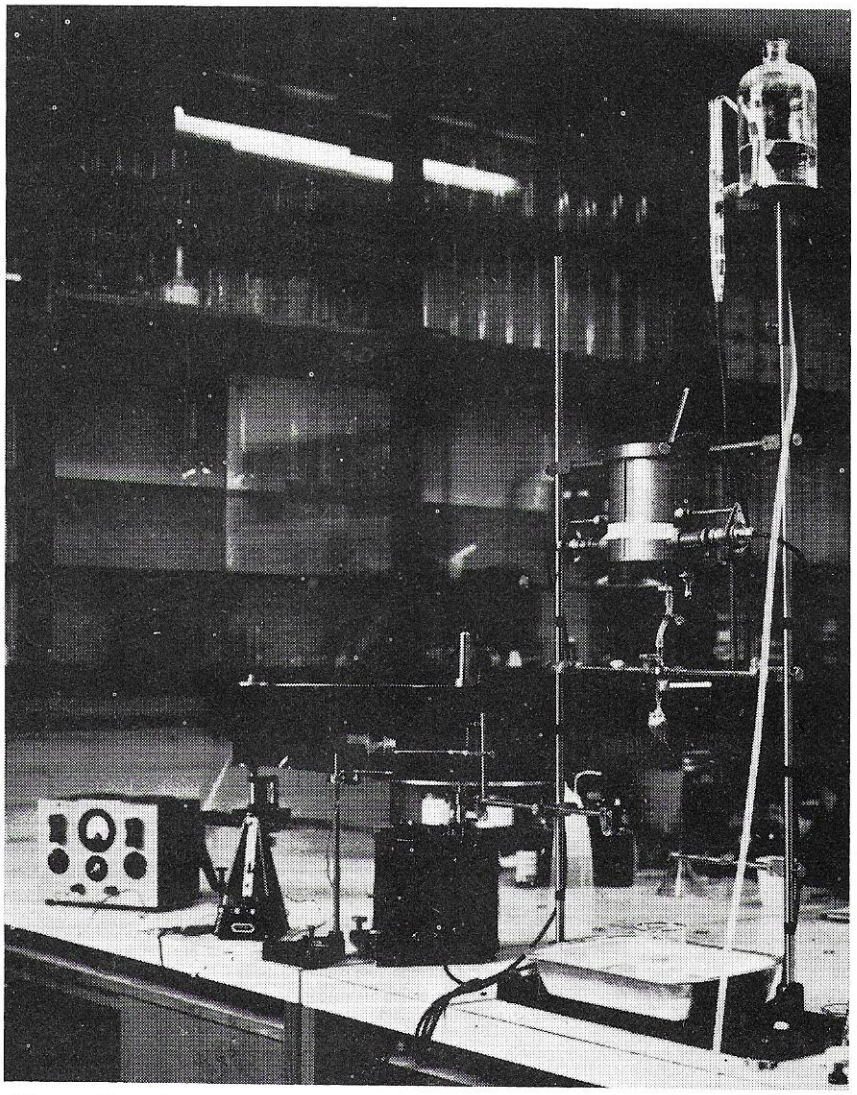


Figure 2 Life support system and (smoked drum) recording apparatus (kymograph).

Dr Holmes carries out the demonstration, assisted by Dr Varley, and he discusses the results. We can assure you that the rabbit being dissected felt no pain whatsoever—its brain was completely dead before the first incision.

There are four stages in the demonstration:

(i) obtaining the heart in as fresh a condition as possible;

(ii) keeping the heart alive when it is no longer inside the animal—this involves linking it to a machine which takes the place of the normal support systems and perfusing it with 'Ringer solution'*;

(iii) recording the rate and strength of heart-beat under different conditions;

(iv) interpreting the results.

** In 1874, Ringer showed that an excised frog heart continues to beat for a prolonged time when it is perfused with a certain mixture of salts of sodium, potassium, and calcium. 'Rabbit Ringer' contains glucose as well as an appropriate mixture of salts.*

Two kymograph (smoked drum) traces of the heart activity are shown below. These are the second set shown in the programme—the ones discussed by Dr Holmes—not the ones you saw being recorded during the demonstration in the laboratory. Turn to *SAQ 21*—this is an exercise based on these two traces.

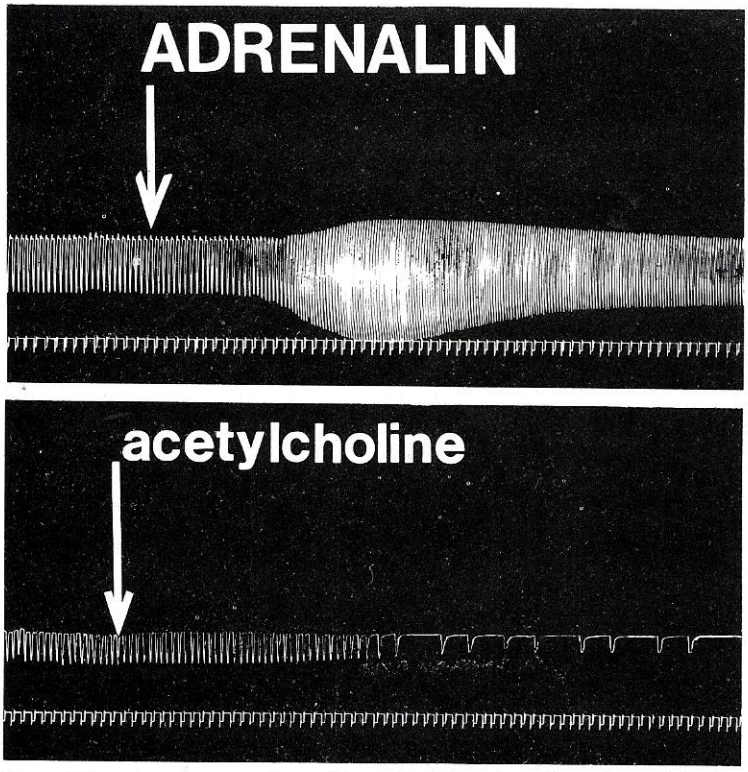


Figure 3 Kymograph traces show effects of adding adrenalin and acetylcholine to the perfusion fluid.

You can read more about cilia and their structure as revealed by the electron micrograph in Hurry, *The Microstructure of Cells*, pp. 30 and 31. If you have time to study black-page Appendix 2 and to carry out the practical work suggested in black-page Appendix 3, you can read about the variety of single-celled organisms living in fresh waters and collect and examine some of these for yourselves. Some of those shown in the films are rare forms—their names are listed below for the benefit of those specially interested, but you are *not* expected to try to remember any apart from *Paramecium, Euglena Amoeba.*

Colour transparencies of these three organisms are included in *filmstrip* 18b—numbers 9, 10 and 12. Strips 18a and b also show many other protistans. Do not attempt to remember their names or the details about them.

Organisms (Protista) seen in Television Unit 18

First Film sequence	*Second Film sequence*	Coleps
Paramecium*	Paramecium*	Dileptus
Euglena*	Opalina	Nassula
Amoeba	Hypotrich ('fleas')	Euglena
Paramecium* (+Stentor)	Stylonichia*	Peranema
	Stentor*	Polytomella
	Carchesium	Amoeba*

The names are given in the order in which the organisms are shown. You are *not* expected to remember their names except of course *Paramecium, Euglena,* and *Amoeba.*

If you have the opportunity to see the broadcast a second time (or are able to see it on the 8 mm film copy in your Study Centre) you might like to try and identify these protistans as they appear.

** In Appendix 2 (Black) of the Main Text of Unit 18 you will find illustrations of the organisms marked*, along with many others to be found in fresh water.*

TELEVISION UNIT 19

Pre-broadcast Notes

Subject
Selection

Speakers
Professor M. J. Pentz
Dr M. E. Varley
Dr R. H. Holmes
Dr Sidnie Manton FRS

The programme concerns selection of well-adapted individuals within populations and mechanisms that keep related species separate. There are three parts:

1 Pale (typical) and dark (melanic) varieties of the peppered moth *Biston betularia* have dissimilar distributions through the British Isles. This is a classical example of natural selection in action today.

2 Two closely related species of tropical fish, *Colisa lalia* and *C. labiata*, do not normally interbreed because they differ in appearance but they share a chemical stimulus to reproduction inherited from a common ancestor. The behaviour barrier to interbreeding is an example of isolating mechanisms essential for maintaining the integrity of gene pools of newly evolved species, allowing their specific adaptations to be passed to their descendants.

3 A new breed (variety) of cat with long fur but the Siamese colour pattern has been developed by a planned breeding programme over 22 years. This is an example of the highly efficient application of genetical knowledge for artificial selection of desirable attributes in domestic animals.

If you are especially interested in the genetics of cats, you should read: *Colourpoint Longhair and Himalayan Cats*, by S. M. Manton (1971), George Allen and Unwin. It includes accounts of the genetics of other cats besides the colourpoint.

Before watching the programme you should read all of Section 19.6 of the Main Text.

Post-broadcast Notes

Dr Holmes talked about the effect of selection on natural populations. He explained how the frequency in a population of a mutant gene with a selective advantage is likely to increase in successive generations until the mutant replaces the original 'wild-type'. In his graph, he used values derived from a study of the peppered moth *Biston betularia*, carried out by Dr Bernard Kettlewell.

Dr Varley demonstrated how moths that fly by night can be trapped. She showed specimens of the two varieties of peppered moth—the pale 'typical' form and the dark 'melanic' mutant. Although they look very different, they are members of the same species, differing in one colour-determining gene only. Using excerpts from a film made by Dr Kettlewell and Professor Tinbergen, Dr Varley demonstrated that the two forms are subject to very different selection pressures in different parts of Britain. The melanic form, rare one hundred years ago, is now the common form where tree trunks are coated with a layer of soot. A certain number of pale forms are still caught in these polluted areas. Dr Holmes explained that these moths may migrate by night so that pale forms from North Wales may be caught by traps in the suburbs of Liverpool. Using values supplied by Professor Sheppard, he modified the curve he showed earlier to take account of migration as well as of selection*.

**With the cleaning up of areas that used to suffer from air pollution, the selective pressures are likely to change and it is probable that the proportion of melanic peppered moths will decrease in the future; indeed there is evidence that this reversal has begun in some areas.*

Success in evolutionary terms means the passing on of an individual's genes to descendants. For many animals, this involves recognition of other individuals of the right species and sex so that viable offspring may be produced. Dr Varley showed striped males and plain silvery females of the small tropical fish species *Colisa lalia*. A male when ready to breed responds to sight of a female by building a floating raft of air bubbles, coated in mucus from his mouth. He then courts the female, they mate and the eggs float up to the bubble 'nest' where they develop. A male will respond to a chemical stimulus from a hidden *C. lalia* by building a bubble nest; he will also respond to chemical stimuli from hidden females of the closely related species *Colisa labiata*. Normally a male *C. lalia* will not build a bubble nest if put with and able to see a female *C. labiata*. When strong chemical stimulation is provided, by circulating water from concealed tanks containing other fishes of their own species, the barrier to inter-breeding breaks down and the two fish mate. The resulting hybrids look different from both parent species and are probably less well-adapted to their habitats than either parent species. The common ancestor of the two species probably lived in muddy water and individuals recognized each other by smell. The modern species live in clear water and have good eyesight; recognition is by visual stimuli. Normally, differences in appearance between *C. lalia* and *C. labiata* are effective in preventing wastage of genes in production of hybrids that are not likely to survive.

Dr Manton's work on the breeding of colourpoint longhair cats is an example of artificial selection – that is, the selection of animals under domestication. In 1947, she started a breeding programme with the intention of producing a good type of longhair (or Persian) cat with the distinctive colour pattern of the (short-haired) Siamese cat, and a temperament with the better features of the two original breeds.

Cats of the two parent breeds – black longhair Persian and shorthair Siamese – differ in hair colour and length; they also differ in shape of face. All the kittens of the first generation were black shorthairs. Breeding pairs of these together produced, on average, among every 16 kittens: 9 black shorthairs, 3 black longhairs, 3 Siamese (shorthairs) and 1 colourpoint (Siamese pattern longhair). The latter breed true for hair length and colour pattern. Of the rest, one black shorthair, one black longhair and one Siamese will breed true while the rest carry (invisibly) the other characters to those seen – so their offspring may include the desired colourpoint if they are mated suitably.

To produce champion colourpoint cats, such as those in the photographs shown in the programme, Dr Manton has outcrossed from her original colourpoints to good Persians and to 'carriers' with the right temperament or good shape of face. She has selected the kittens most suitable for her programme and arranged appropriate matings for them. Now, after about 8 generations of selection and inter- and cross-breeding, she has established a breed of charming cats that are also very successful in winning championships.

Dr Manton produced photographs of the original Persian and Siamese cats and their black-haired offspring and showed some of her colourpoint cats, pointing out their special features. In addition, she showed two 'self-coloured' varieties produced by breeding together carriers of special genes that modify the Siamese pattern. She ended with a group of kittens – potential champions produced by 22 years of selective breeding.

TELEVISION UNIT 20

Pre-broadcast Notes

Subjects
Behaviour of a Parasitic Insect, Handling Fruitflies, and North Sea Plaice Fisheries
Speakers
Professor M. J. Pentz
Dr M. E. Varley
Dr R. M. Holmes

The structure of natural communities is the result of interrelationships between organisms; many of these depend on highly specific behaviour patterns. The balance between different populations of organisms is a delicate one and it is easily disturbed.

Part 1 shows how some aspects of the behaviour of the ichneumonid wasp *Nemeritis*, whose larvae are parasites of flour moth caterpillars, can be studied in the laboratory.

Part 2 shows how to abstract the fruitflies (*Drosophila*) that you may collect or breed in your jars of banana mash during your Home Experiment.

Part 3 shows how populations of plaice in the North Sea are affected by the predatory activities of fishermen.

Text. The following Sections of the text should be read before viewing the programme:

20.3, 20.4, 20.6 and Home Experiment Notes (and look at filmstrip 19/20 (a) 1 to 5).

Parasitic insects such as *Nemeritis* often act as regulating factors on the populations of their host insects; this implies that the numbers of parasites relate to those of their hosts in a way that is directly or, more often, delayed density-dependent. The relationship results from specific behaviour patterns of the parasite especially when it is about to lay its eggs. It is essential in some experiments to know whether or not the parasite lays an egg in a particular caterpillar—how can we deduce this?

Before starting your Home Experiment, you may find it useful to watch this demonstration of how to extract flies from your jam jars and to see what the flies, maggots, puparia and parasites of *Drosophila* look like when alive.

Fishermen exploiting the plaice of the North Sea are hunters preying on a wild population of fish. People tend to believe that more efficient methods of catching fish must lead to greater returns and that any increase in effort must result in increased catches. But is the plaice population of the North Sea an unlimited resource? If it is not, how can we protect the stocks and yet maintain a good yield of fish?

Post-broadcast Notes

Summary of Part 1

Nemeritis probes into flour with her long ovipositor. When this penetrates into a flour moth caterpillar, the insect may or may not lay an egg. If she

does, then she must stop and manoeuvre another tiny egg into the tip of her ovipositor before she starts to probe again. Careful observation reveals that every time she moves another egg into position, she makes a very characteristic 'cocking' movement. By watching for this, we can tell whether or not she has just laid an egg. Her behaviour reveals an economy in the laying of eggs which should result in more efficient parasitization of a flour moth population by a population of its parasites. *Nemeritis* can detect whether or not a flour moth caterpillar already contains a parasite egg. The parasites can locate host caterpillars when these are hidden under gauze.

Summary of Part 2

When *Drosophila* adults are disturbed, they fly upwards and towards light – this behaviour makes it simple to abstract them from jam jars. The live parasite is quite similar in general appearance to *Nemeritis* to which it is related; it is about the same length as adult *Drosophila*.

Summary of Part 3

Statistics of landings of plaice from the North Sea show that increased effort may give increased returns for a few years but then catches fall off, to rise again after the sort of 'rest' provided by a war – so the plaice populations are not an unlimited resource but must be exploited carefully to conserve the stocks. In the model, the ball bearings represent fish. For each size group, the catch consists of those balls that are held back; the balls that roll into the next compartment are the stock that survive to grow larger and be fished in later years. Some of these fish would die and this mortality is not shown in the model.

Dr Holmes showed that a lower effort (or a method of fishing that takes a smaller percentage of the stock) actually results eventually in a greater weight of fish being landed from a year-group of fish.

The simple formula he used is given in *Population Dynamics*, p. 52. In theory, it is possible to increase the yield of North Sea plaice by increasing the growth rate of the fish G, and by increasing the numbers of young fish entering the catchable stock A. In practice, methods for achieving these results are not, at present, economically viable. We show a film of plaice before and after 'metamorphosis' (change in shape from a symmetrical planktonic larva to an asymmetrical bottom-living flatfish): this was taken in a 'fish farm'. The most practical way of protecting wild stocks is to set by law a minimum size to the mesh that can be used when fishing; this is a way of manipulating the numbers of young fish caught C. We show an extract from a famous film that first demonstrated to sceptical fishermen that small plaice escape through the stretched mesh of the 'cod end' while the larger fish are trapped.

TELEVISION UNIT 21

Pre-broadcast Notes

Subjects
An Evolutionary Tree, Types of Swimming Movement in Vertebrates, Biochemical Unity and the Origin of Life

Speakers
Professor M. J. Pentz
Professor S. P. R. Rose
Dr M. E. Varley

This Unit's TV programme, like the text, is concerned with aspects of evolution. Part 1 shows you one possible solution to Home Experiment 2. Part 2 relates the pattern of swimming in various vertebrates to the structure of their skeletons and particularly of their backbones. Part 3 concludes the purely biological part of the course with speculation about the origin of life.

Text: the following Sections of the text should be read before viewing the programme: 21.2, 21.3, 21.4, 21.6, 21.7, 21.8 and the notes for Home Experiment 2. Look back at the notes for the Home Experiment for Unit 13 since Professor Rose will refer to chromatography.
You should attempt Home Experiment 2 before watching the programme, so that you will follow more easily the solution devised by Professor Pentz. He will arrange the collection of objects to make an 'evolutionary tree'.

Ancestral vertebrates lived in water and swam. Among their descendants are groups of terrestrial animals that move on land, usually with limbs; some of these have returned to water and to the swimming habit. Comparison of different groups of swimming vertebrates reveals convergence and divergence.

The great similarity of the biochemical processes of organisms gives strong support to the theory of a common origin of all life on Earth. One possible theory is supported by Miller's experiments; we show the type of apparatus that he used.

Post-broadcast Notes

Summary of Part 1

Your class tutors have a description of an evolutionary tree similar to that demonstrated by Professor Pentz. You can compare it with your own by using the letters denoting the various objects.

Summary of Part 2

Most fish swim by bending the body from side to side and so moving the tail horizontally; the movement is made more precise by the action of fins. Salamanders walk by bending the body from side to side using the limbs as struts; in water they hold the limbs against the body and swim by sideways bending movements of the body and tail. A grass-snake moves on land and in water by similar sideways bending movements; its backbone consists of many similar vertebrae jointed together in a way that permits these movements and prevents others. The earliest reptiles probably moved like salamanders with their bodies close to the ground and limbs held out sideways as in modern lizards. Two extinct groups were probably efficient swimmers – the fish-like ichthyosaurs with sideways movements

of the tail and the long-necked turtle-like plesiosaurs with a more rigid body but well developed paddle-like limbs.

In mammals the body is held above the ground with the limbs below it. The backbone is divided into regions and the vertebrae are specialized with the result that different sorts of movement are confined to special regions. The lumbar vertebrae, just in front of the hind legs, allow up and down movement only, seen very well in greyhounds and the cheetah. Swimming in mammals is either fish-like but with the tail moving vertically, or the result of paddling with modified limbs.

Terrestrial vertebrates can display many habits, illustrating divergence; when they swim, they either show convergence to fishes or have paddle-like limbs that illustrate convergence between, for example, a turtle and a seal.

Summary of Part 3

Paper chromatography, which you used in Home Experiment 13, is an elegant technique for analysing mixtures containing, for instance, amino acids. One method separates the spots so that they spread out in two dimensions. In this way, Miller analysed the products of his experiment. Essentially he started with a hot, closed system containing steam, ammonia, carbon dioxide and methane. He added energy in the form of a continuous electric discharge. The resulting chemical reactions produced traces of many organic substances, including amino acids; in fact, there was abiotic synthesis of substances normally produced only by living cells. You will learn more about the Earth's primitive atmosphere and its evolution when you study the Earth Science Units.

Professor Rose concludes the programme by recapitulating some of the characteristics of life and stressing the fascination to a biochemist of the basic unity of life processes.

TELEVISION UNIT 22

Pre-broadcast notes

Subject
Earth Structure

Speakers
Professor M. J. Pentz
Professor I. G. Gass
Professor F. R. Stannard

The object of this programme is to illustrate and amplify several of the topics of the Main Text of Unit 22; and in this sense parts of the Main Text itself may be regarded as the Broadcast Notes for the programme. We hope that the programme will clarify certain of the points you may have found obscure or certain things which can simply be better illustrated in three dimensions than in two. Obviously, then, the Main Text must be studied before the programme.

Note At the beginning of the programme Professor Pentz refers to 'Figure 13' in the Main Text. Since the TV programme was made the text figure numbers have been changed – the relevant diagram is now *Figure 9*.

The main contents of the programme are:

(i) a physical demonstration of the nature of P and S waves;
(ii) a discussion and demonstration of the pattern of P and S waves emanating from a fault such as the San Andreas Fault – with special reference to Figure 9 in the Main Text;
(iii) practical seismometers and their operation;
(iv) earthquake traces and wave paths through the Earth;
(v) the structure of the Earth, including the low velocity layer.

Post-broadcast notes

Professor Stannard discussed the physical nature of P and S waves both diagrammatically and using a model comprising three springs. The differences between P and S waves were then illustrated by special reference to the San Andreas Fault, again using the three-spring model. Professor Stannard also paid particular attention to the *pattern* of waves emitted from a fault.

Professor Gass next demonstrated the operation of seismometers. At any measuring station, three seismometers are required to measure an earthquake wave completely – (i) one measures the P waves in the vertical (V) direction; (ii) the second measures S waves in the north-south (N-S) direction; and (iii) the third measures the S waves in the east-west (E-W) direction.

Professor Gass then went on to show several seismometer traces from real earthquakes. Then followed a more theoretical discussion of the transmission of earthquake waves through the Earth. By tracing waves through the Earth the overall structure and some of the physical properties of the Earth may be determined. Professor Gass also paid particular attention to the low velocity layer in the Earth – a very soft layer which is useful to explain how the Earth's lithosphere moves and why basalt magma rises to the Earth's surface.

TELEVISION UNIT 23

Pre-broadcast Notes

Subjects
1 Palaeomagnestism
2 The Self-exciting Dynamo
Speakers
Professor M. J. Pentz
Dr Peter J. Smith
Professor R. L. Wilson
Dr F. J. Lowes

The programme is divided into two sections, the first taking about 80 per cent of the time and the second about 20 per cent.

Part 1

This part of the programme is about *palaeomagnetism*, the study of the magnetization of rocks. Before viewing it you should have read at least Section 23.3.5 of the Main Text of Unit 23. However, because Section 23.3.5 is better read, not in isolation, but as an integral part of the whole text, you will not get the most value from this part of the programme unless you have read to the end of Section 23.3.9. Only if you have done this, will you be able to see why palaeomagnetism is important in the context of the complete study of the Earth's magnetic field.

As far as palaeomagnetism is concerned, the text of Unit 23 deals only with basic theory and results. The overall object of this part of the pro-

gramme is thus to give you some insight into the practical aspects of palaeomagnetism – in other words, *how* rocks are used to determine the direction of the Earth's ancient magnetic field.

You will see how a rock core is collected in the field, how it is oriented with respect to a fixed co-ordinate system on the Earth's surface, how its direction of magnetization is measured in the laboratory, and how the direction of magnetization is combined with the orientation data to determine the direction of the Earth's magnetic field at the place where the rock was collected and at the time the rock was laid down.

The collection and orientation is carried out by Dr Peter J. Smith, Senior Lecturer in Earth Sciences at the Open University, the rock in question being a Tertiary basalt lava flow from Ballycastle, Northern Ireland. The measurement of the rock is carried out by Professor R. L. Wilson, Professor of Geophysics at the University of Liverpool, in his laboratory at Liverpool.

The astatic magnetometer

The magnetization of the rock core will be measured on an *astatic magnetometer*. The programme will thus be of greater value, interest and clarity to you if you know beforehand a little about how this instrument works.

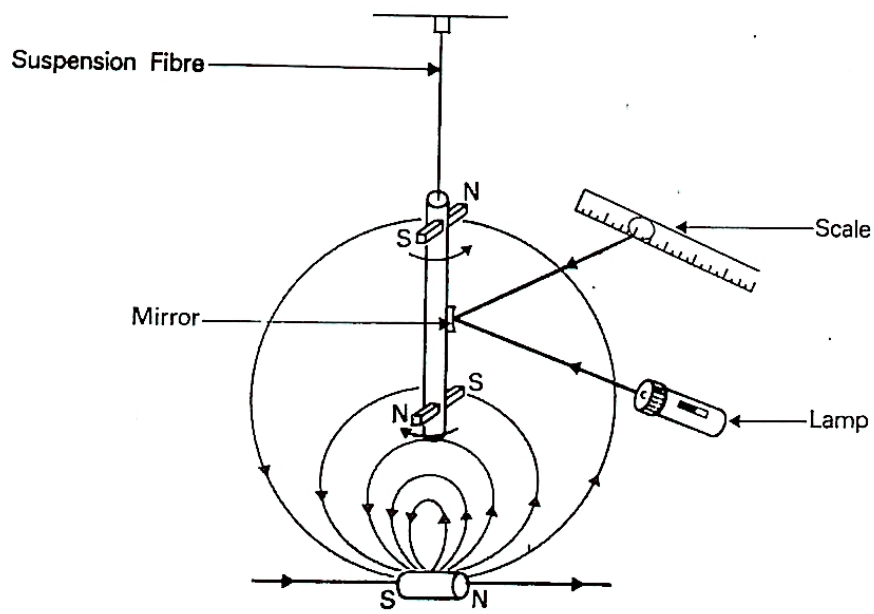


Figure 1 The principle of the astatic magnetometer.

The simple astatic magnetometer consists of two small permanent magnets fixed to a light rigid rod which is suspended by a fine fibre (see Fig. 1).

The magnets are exactly equal in dimensions and strength and are arranged so that they are exactly opposite in direction. The significance of this arrangement is that a uniform magnetic field has no effect upon the system. (A uniform magnetic field is one which is everywhere equal in strength and direction. For example, over the small region occupied by the instrument – the rod is usually a few centimetres long – the Earth's magnetic field may be considered uniform.) Such a field has no overall effect because, although each magnet tries to turn so that it aligns itself with the field, with the N poles pointing in the direction of the induction,

the magnets will tend to turn in opposite directions. Because the magnets are equal in strength, the net effect is thus to leave the system stationary.

But consider what happens when a magnetic object such as a rock is placed just below the lower magnet. Because the rock is closer to the lower magnet, the strength of the magnetic field produced by the rock at the position of the lower magnet will be greater than the strength of the field at the upper magnet. In other words, as far as the astatic system is concerned the field is no longer uniform. Thus, although the magnets will still try to turn in opposite directions, the lower magnet will try to turn one way more than the upper magnet will turn the other way. As a result, the whole rod/magnet system will rotate; and the greater the strength of the magnetization in the rock the further the rod will rotate. The angle through which the rod rotates is thus a measure of the magnetic strength of the rock.

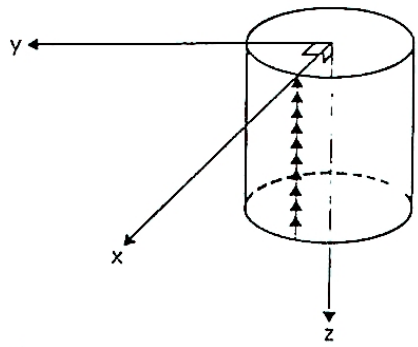


Figure 2 Definition of core axes.

In the simple instrument, the rotation of the rod is measured by means of a light beam reflected from a mirror fixed to the rod (Fig. 1). In the magnetometer that you will see, the measurement of rotation is more sophisticated. However, you do not need to worry about these details.
(*Study Comment* Do not worry if you find difficulty in understanding the next paragraph – and certainly do not waste time on it. It describes what, in one sense, may be regarded as a detail in the context of this programme. All you need remember when viewing the programme is that to determine the direction of magnetization in the rock, it is necessary to measure the sample in three different positions.)

The astatic magnetometer measures the strength of the rock magnetization in one direction at a time. The instrument in Figure 1, for example, is measuring the component of magnetization along the main axis of the core (the Z axis in Fig. 2). To obtain the *direction* of magnetization in the rock it is necessary to measure the *strength* of the magnetization along three separate directions at right angles (X, Y and Z), and then combine the results trigonometrically. To make the calculations simpler the axes X, Y and Z are defined with respect to the orientation line on the rock core as shown in Figure 2. You will understand the significance of the orientation line after you have seen the programme.

Student Activity

1 Inevitably this programme contains many practical details; but you are not required to remember them all. What are important are the *principles* involved – in other words, the main steps in the process of collecting and measuring the rock and the reasons for these steps. After the programme has ended you will be asked to make a list of these essential steps. You should therefore try to isolate them as the programme proceeds.

2 During the orientation of the rock core in the field you will be asked to jot down two angles as they are measured. Later, in the studio, the significance of these angles will be explained more fully in diagram form. The angles are (you can enter the numerical values):

(i) angle between the horizontal and the orientation line on the core= . . .

(ii) angle the orientation line makes with the distant headland= . . .

(You do not need to remember these angles after the programme has finished.)

Part 2

In this part of the programme, Dr F. J. Lowes of the School of Physics, University of Newcastle upon Tyne, describes the world's only working model of a self-exciting dynamo, built by himself and Dr I. Wilkinson. Before viewing this part of the programme you should have read Sections 23.4, 23.4.1 23.4.2, 23.4.3 and 23.4.4 of the Main Text of Unit 23.

Post-broadcast Notes

Part 1

In this part of the programme you saw how the palaeomagnetic process works. Seven important and essential steps were involved of which the first was, of course, the drilling and recovery of the rock core. You should now make a list of the *remaining six* steps. Remember that we are only interested here in the *key* points.

Part 2

The object of this part of the programme was to demonstrate to you that it is physically possible to construct a self-exciting dynamo. Two cylinders of suitable material rotating at an angle in blocks will produce a magnetic field which will, moreover, reverse spontaneously and repeatedly. However, you should not think that the Lowes-Wilkinson dynamo is anything like the dynamo in the Earth's core which is thought to produce the Earth's magnetic field. The moving part in the real Earth dynamo is the fluid core material itself (analogy in the mechanical dynamo: the rotating cylinders); and the energy which keeps the core material moving is probably either thermal or precessional (analogy: the electric motors which keep the cylinders rotating). The point of trying to build a self-exciting dynamo in the laboratory is not to simulate what actually happens in the Earth, but simply to show that the self-exciting dynamo concept is not just a nice theoretical idea with no chance of being practically viable.

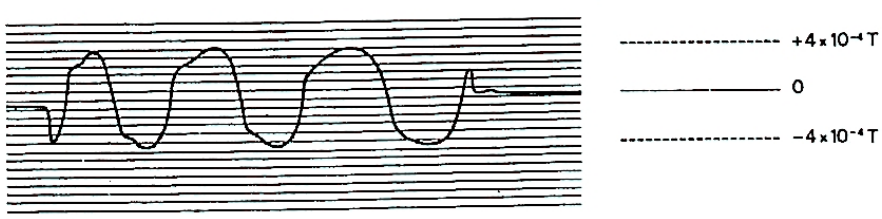


Figure 3 Chart recording of field reversals produced by the Lowes-Wilkinson self-exciting dynamo. The scale refers to the strength of the magnetic field at the position of the magnetic compass seen in the programme.

The chart recording showing the field reversals (mentioned by Dr Lowes in the programme) is shown here as Figure 3; and the diagram showing the cylinder arrangement is shown in Figure 4.

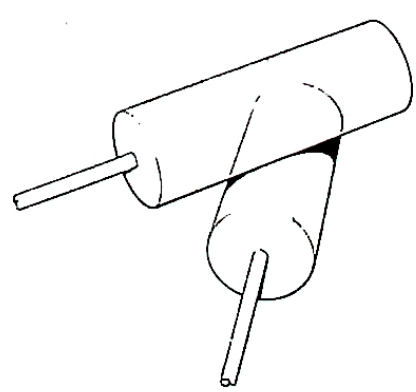


Figure 4

TELEVISION UNIT 24

Pre-broadcast Notes

Subjects
(i) *Geological Cycles*
(ii) *Isostasy*
(iii) *Palaeomagnetic Evidence of Continental Drift*

Speakers
Professor M. J. Pentz
Professor I. G. Gass
Dr R. C. L. Wilson

(i) *Geological cycles*

A geological process, such as the weathering of limestone, forms part of the geological cycle. Several components of this cycle are described at the beginning of Unit 24.

The weathering of limestone is a mixture of physical and chemical processes which affect the rock in place and do not involve transportation of material.

The TV programme considers this process and shows how fractionation of weathering products can occur. But what happens then? Dr Wilson takes one of the fractions from the weathering process and asks the student to construct for himself a geological cycle involving this fraction.

The aim of Section 24.1 of this Unit is to show how the various geological cycles overlap and fit into each other. The TV programme takes a simple example of a geological process – the weathering of limestone – and shows by analogy how its products are fractionated and re-cycled by geological processes.

Before watching

Read Section 24.1 of Unit 24. The chemical equations below summarize what happens to the limestone in the part of the geological cycle described in the programme. A knowledge of these equations would be invaluable when following the laboratory processes demonstrated by Dr Wilson. (Note: they are much simplified.)

1 *Why rain water is acid*

$$H_2O + CO_2 \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$$

carbon dioxide — *carbonic acid*

2 *Why limestone dissolves*

$$CaCO_3 + 2H^+ + 2HCO_3^- \rightarrow Ca(HCO_3)_2 + CO_2 + H_2O$$

limestone — *soluble calcium salt*

3 *Why a calcareous sediment forms on the sea-bed*

$$Ca(HCO_3)_2 \rightarrow Ca\,CO_3 + CO_2 + H_2O$$

calcium carbonate precipitate

The CO_2 content of sea water is lowered by a rise in temperature (CO_2 is less soluble at higher temperatures) or by extraction during photosynthesis, and so this reaction proceeds to the right.

(ii) *Isostasy*

It seems logical that, just as a block of wood floating undisturbed in water is said to be 'in balance with its surroundings', a continent floating undisturbed in the Earth's mantle should be said to be in balance in the same way. But what happens when some force, deep within the Earth or even

on the surface itself, disturbs this position of balance? To answer this Professor Gass uses a simple model to demonstrate the principle of isostatic readjustment.

The TV programme continues with the problem of how Earth scientists can tell if a continent is trying to regain equilibrium. One solution to this problem is by studying measurements of the Earth's gravity. Gravity measurements are not compatible over the Earth's surface, but in fact consist of a series of positive and negative anomalies. Professor Gass outlines one reason why this is so. By referring to a survey of such gravity anomalies around the Gulf of Bothnia, he shows how these measurements relate to the isostatic readjustment taking place in the area.

The mechanism through which isostatic readjustment takes place might present some difficulty. Professor Gass considers two ideas of this mechanism and introduces a new concept, that of 'phase change', in a very visual way.

Before watching

To follow the argument in this part of the programme, it is essential to have two scientific facts at the back of one's mind. The first is concerned with density and is simply this: a material of low density will float in high density material. Thus, wood floats in water; iron floats in mercury; a land mass of light rocks is supported by heavier rocks.

The second scientific fact is concerned with the measurement of gravity. The gravitational force of attraction between two masses m_1 and m_2 is inversely proportional to the square of the distance, r, between them.

Thus:

$$G \propto \frac{m_1 m_2}{r^2}$$

If we are measuring the Earth's gravity G_0 then we are measuring the force of attraction between a small mass m_1 in our gravity meter and the much larger mass m_2 of the Earth beneath the gravity meter.

This would be fine if the Earth was a perfect sphere and composed of material of uniform density. But, as you know, this is not the case and local conditions determine the values of G that we obtain. The definition of an *absolute* value of G_0 is beyond the scope of this Unit but, taking all this for granted, measurements of gravity in a survey can be expressed *relative* to G_0 as positive and negative gravity anomalies. But it is the interpretation of these anomalies with which we are concerned in this programme.

Finally, we should like you to conduct your own gravity survey on the areas illustrated in Figure 1, and to express the values G_1, G_2, G_3 as positive or negative gravity anomalies.

Figure 1 is on p. 68.

(iii) *Palaeomagnetic evidence of continental drift*

As a trailer for the next TV programme, Dr Wilson reviews the palaeomagnetic evidence for continental drift. The evidence is particularly important as it shows when the continents began to drift apart.

Before watching

Palaeomagnetism was introduced in Unit 23. It would be useful to look back at the relevant sections in that Unit before seeing how palaeomagnetic

data have been applied to this problem.

Chapter 15 in *Understanding the Earth* is devoted to continental drift. Palaeomagnetic evidence is described on pp. 222–3. If you have any difficulty in understanding this section, particularly the significance of Figure 15.10, then Dr Wilson's demonstration in the TV programme will be invaluable.

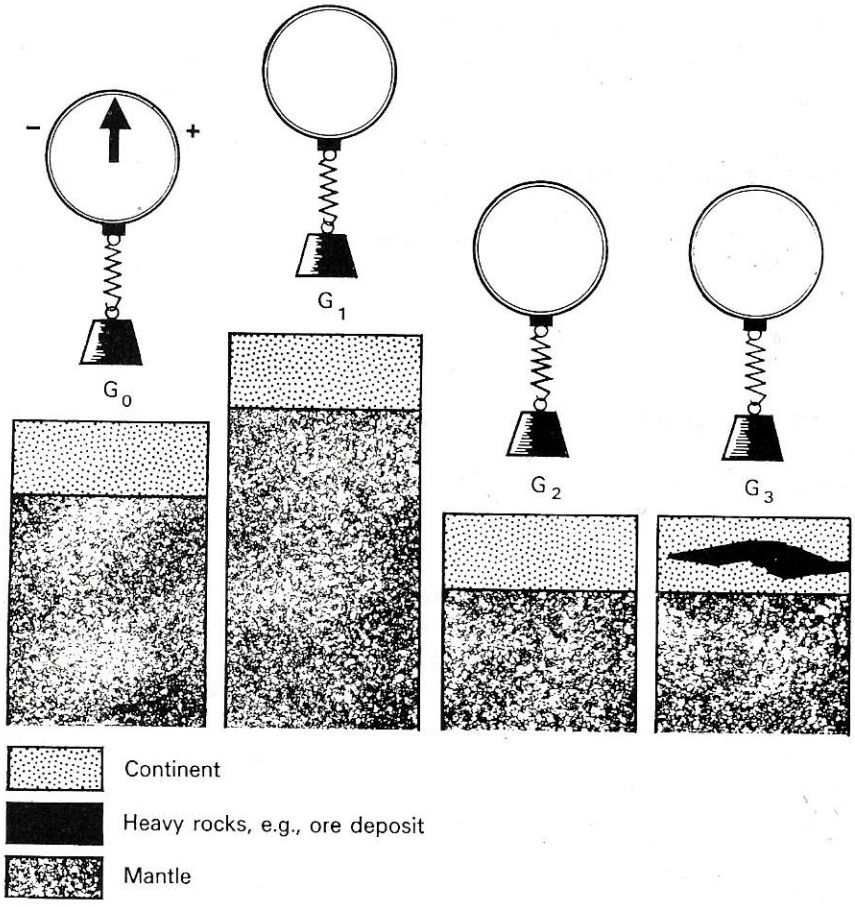


Figure 1

Post-broadcast Notes

(i) *Geological cycles*

Dr Wilson illustrated the process of weathering by dissolving limestone in dilute hydrochloric acid, and showed that this produced four fractions (Fig. 2). He suggested that the breakdown of limestone in the beaker was analogous to weathering, a geological process whereby rocks are broken down, *in place*, by physical and chemical processes. In the real situation, other minerals can be broken down, by 'acidic' rainwater for example, (again, the reaction is much simplified) and you are *not* expected to recall the details.

$$6H_2O + CO_2 + 2KAlSi_3O_8 \rightarrow \begin{matrix} Al_2Si_2O_5(OH)_4 \textit{ clay mineral} \\ 4\ SiO(OH)_2 \textit{ silicic 'acid'} \\ K_2CO_3 \textit{ solution} \end{matrix}$$

orthoclase feldspar

So, just as in the laboratory analogy, weathering produces different *fractions;* in this case, a clay mineral (fine-grained residue) silicic 'acid', which is not very soluble and may be precipitated as silica, and a solution of potassium carbonate, which will be easily removed. Similarly, a *rock* composed of several minerals, will be fractionated by weathering into several parts:

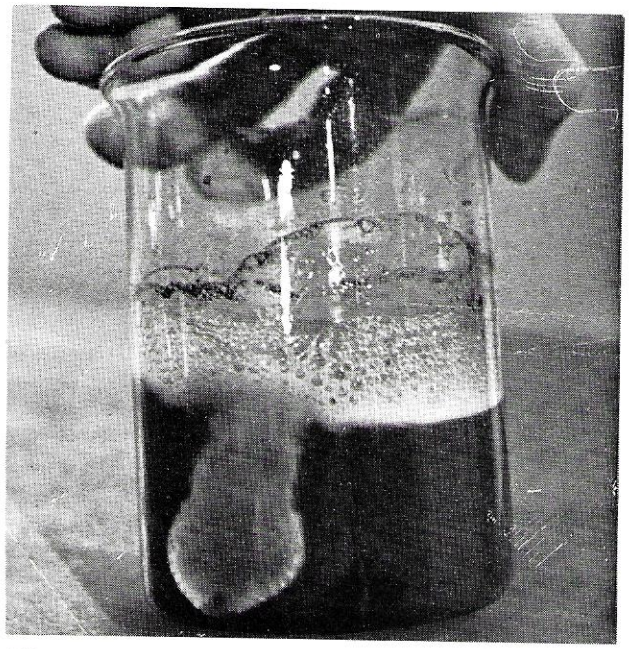
GRANITE ——→ weathering ——→ WEATHERING PRODUCTS

quartz – SiO_2
orthoclase – $KAlSi_3O_8$
albite – $NaAlSi_3O_8$
mica(muscovite) – $KAl_2(OH)_2Si_3AlO_{10}$

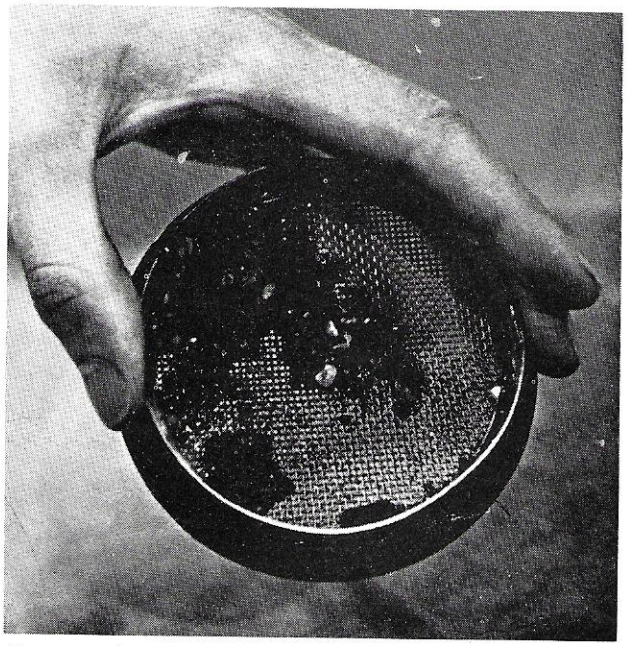
1 quartz – (unaffected by chemical weathering)
2 Clay minerals – (these may break down to give aluminium oxide)
3 Solutions – especially Na_2CO_3 and K_2CO_3

In this simplified example, the granite has given a coarse-grained residue 1, a fine-grained residue 2, and a solution 3. These weathering products will be further separated during transport: obviously a solution is

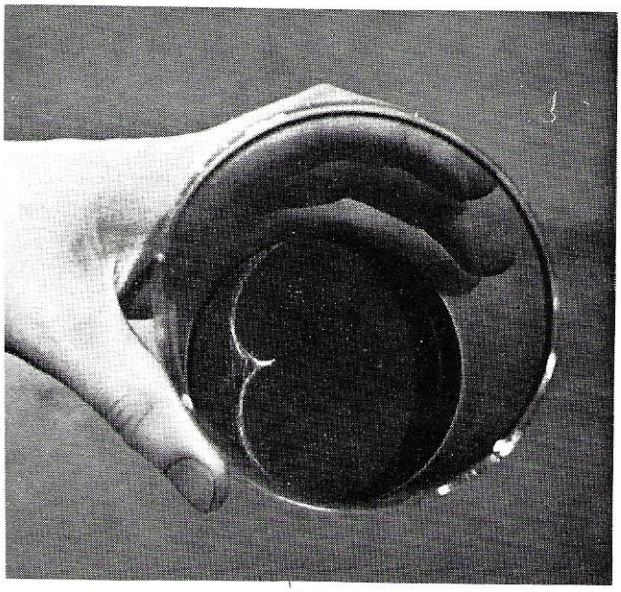
Figure 2



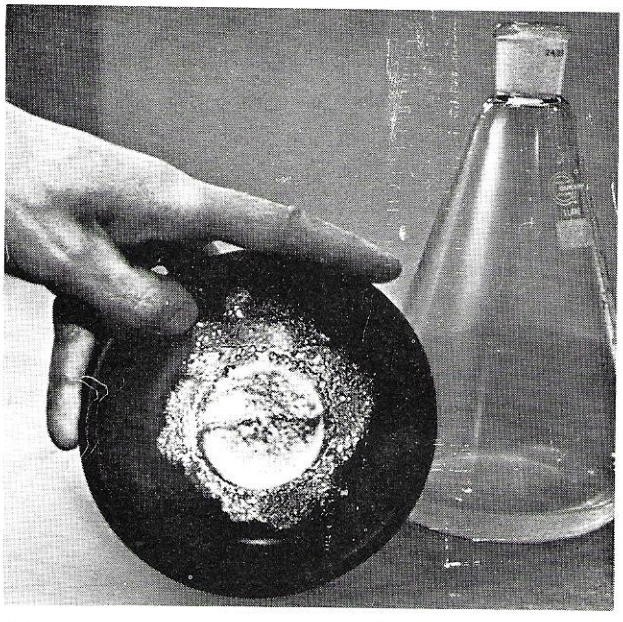
CO_2 gas



Coarse residue



Fine residue



Solution

easily washed away, and finer particles more likely to be washed away than coarser ones – Dr Wilson made this point during the programme. In this discussion, we have not discussed in great detail processes of chemical weathering. They are complicated by the role played by the decay of organic material, which often makes water in soils quite acidic. In fact, in tropical areas, where the rainfall is high and there is much dead plant material, conditions are such that even quartz (SiO_2) will be dissolved, and only aluminium oxide (and also iron oxides, if the original rock contains iron minerals) will remain, giving *bauxite*, which is an aluminium *ore* (see TV Notes, Unit 27).

Dr Wilson examined what happens to one fraction. He chose the solution, and showed how the calcium in it became fixed once more into rocks and then came full circle to be released once more into solution by weathering. Try and complete the details of this geochemical cycle of calcium from the information given in the programme (Fig. 3).

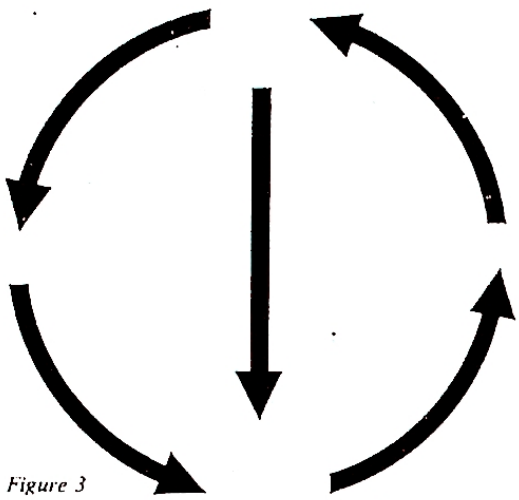


Figure 3

limestone
shells
mud

Put the above products, mentioned in the programme, into the correct places between the arrows.

Having reminded yourself of the items discussed in the programme, answer the following questions.

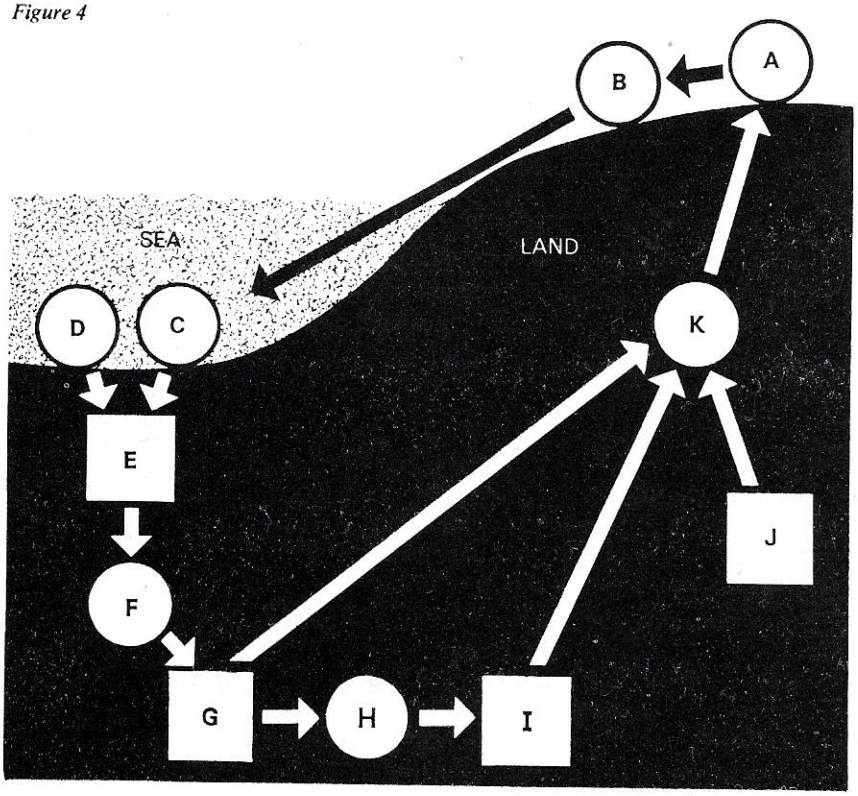
1 Complete the diagrammatic summary (Fig. 4), of the geochemical cycle of calcium by matching items in the numbered list with the letters on the diagram on the next page.

2 What is the difference between the items you put in circles, and those in boxes?

3 Look at the table on p. 14 of *Understanding the Earth*. Which minerals will contribute calcium to the cycle when they are weathered?

Answers are at the bottom of p. 71.

Figure 4



(i) Metamorphism
(ii) Sediment
(iii) Transport
(iv) Other rocks containing calcium
(v) Limestone
(vi) Precipitation by physico-chemical processes
(vii) Uplift
(viii) Weathering
(ix) Calcareous skeletons
(x) Burial
(xi) Metamorphic rock (marble)

(ii) *Isostasy*

Professor Gass showed a simple model analogy of isostasy – a block of wood floating in water. He then set out to explain, in terms of the concept of isostasy, why mountains tend to remain features of positive relief, and depressions (sedimentary basins) continue to subside.

Professor Gass then went over the two main theories which attempt to explain isostatic movement – the 'flow' theory, and the phase change theory. For the latter case, he explained phase changes by showing graphite and diamond – both the actual materials, and atomic models of them. This theory is explained in the text of Unit 24, and Figures 9 and 10 in Unit 8 show the differing atomic structure of the two minerals. *Remember that the graphite-carbon phase change was used as a simple analogy to explain what might happen to silicate minerals in the Earth.*

(iii) *Palaeomagnetic evidence for continental drift*

Dr Wilson showed how a *polar wandering curve* is plotted from successive determinations of palaeomagnetic pole positions. He took as examples the polar wandering curves of Africa and South America, and showed how the earlier parts of them coincide, and that the later divergence indicates that the two continents began to drift apart about 100–150 Ma ago.

Answers to questions on p. 70 (you are not expected to recall the details):

Q.1 You should have matched: (i) H; (ii) E; (iii) B; (iv) J; (v) G; (vi) C; (vii) K; (viii) A; (ix) D; (x) F; (xi) I.

Q.2 Circles are geological *processes*, boxes are *products*.

Q.3 Anorthite, augite, hornblende.

TELEVISION UNIT 25

Pre-broadcast Notes

It is suggested that for this week you may wish to view the TV programme before reading the text of Unit 25. The subject matter is fully covered in the Unit, but it is hoped that some of the contents will be made more readily understandable by their treatment on television. However, before watching it would be helpful if you reread Sections 23.3.8 and 23.3.9 of Unit 23 on the changes in geomagnetic induction, field reversals, and on how the polarity time-scale is determined by the radiometric dating of continental lava sequences.

Have a look at the Atlantic Chart and trace out the Mid-Atlantic Ridge.

Finally, there is a point which might cause confusion: normally magnetized and reversely magnetized rocks on the seafloor are referred to as producing positive and negative anomalies, respectively. These are *magnetic* anomalies and should not be confused with positive and negative *gravity* anomalies mentioned last week.

Subjects
1 Sea-floor spreading
(a) magnetic strip anomalies
(b) spreading rates
(c) transform faults
2 Plate tectonics
(a) global pattern of seismic activity and aseismic plates
(b) thermal convection as a mechanism to provide energy requirements for plate movement

Speakers
Professor M. J. Pentz
Professor I. G. Gass
Dr Peter J. Smith

Post-broadcast Notes

Summary of Content

By 1960, technological developments made it possible to measure the magnetization of rocks on the ocean floor by dragging a magnetometer behind a ship. When the recorded magnetic anomalies were plotted on a map three important factors emerged.

1 The anomalies were found to form a series of parallel linear strips.
2 Across a ridge crest the pattern of anomalies was symmetrical: one side was the mirror image of the other.
3 The anomalies were interpreted as being due to the alternation of normal and reversed magnetization directions in the oceanic basalts.

These findings can best be interpreted by invoking sea-floor spreading by which basaltic magma originating in the mantle upwells towards the ridge crest, becomes magnetized in the direction of the magnetic field, solidifies and is forced to either side.

A finite spreading rate can be calculated because:

1 The age of the oceanic rocks can be approximated. The pattern of oceanic anomalies is qualitatively exactly the same as the polarity time-scale determined for continental rocks, and can therefore be correlated.
2 The distance from the ridge to the edge of the anomaly can be measured.

Spreading rates vary along the length of a ridge system. For example, the distance from the centre of the Mid-Atlantic Ridge to the continental margin differs markedly along its length. These differences in spreading rate are accommodated by movements along transverse features which repeatedly cut across the main axis of the ridge, offsetting it slightly. This feature is a new class of fault and has been called a transform fault (see Appendix 3 of Unit 24). The transform fault is shown to be seismically active between the offset ridge axis where the ocean floor is moving in opposite directions.

On a global scale it is demonstrated that seismic events are restricted to particular areas—to active ridge crests, transform faults, trench systems and young fold mountain systems. Outside these restricted zones there are vast areas with little or no seismic activity—areas which behave like huge quasi-rigid plates.

Seismic activity is related to relative movements between the plates. From studying the first motions of earthquakes, the direction of plate movement can be determined. The rubber model demonstrated by Professor Gass suggests the alternative hypotheses for what happens when two plates meet:

(i) crumpling and upthrust;
(ii) movement of one plate under another;
(iii) a combination of (i) and (ii).

To try and find out just what is happening at plate margins, a cross-section extension extending from the East Pacific Rise through South America to the Mid-Atlantic Ridge is examined in detail. It appears that the third hypothesis is best, suggesting that after initial crumpling one plate dives down under the other.

But what is the process or mechanism operating so that sea-floor spreading can be initiated and maintained? Many consider that some form of thermal convection can provide the energy requirements. But does it involve total mantle convection, or is it restricted to the low-velocity layer? Both theories pose problems!

A laboratory convection model devised by John Elder in his Cambridge laboratory suggests that it is rather difficult to get simple convection patterns (as the Earth's surface features suggest) from uniform heating from below. This is a laboratory situation and not the Earth—but it does suggest that thermal convection may not be the answer.

TELEVISION UNIT 26

Pre-broadcast Notes

The programme examines a coastal environment and shows how processes occurring within it are producing sediments, thus giving clues to the interpretation of the geological record.

Subjects
Earth History I
The Coastal Environment
The Present is the Key to the Past

Speakers
Professor M. J. Pentz
Dr R. C. L. Wilson

BEFORE THE PROGRAMME make sure you have completed Section 1 and Appendix 3 of the text of Unit 26. In addition, have Figure 14 open beside you whilst viewing.

Post-broadcast Notes

Summary

The main features of the coastal area examined during the programme are described in Appendix 2 of this Unit, so only the major points made need to be summarized here. These were dealt with in the following order:

(i) the traverse across the coastal area, from low- to high-tide mark;

(ii) the significance of grain-size measurements: size distribution differences between environments (Fig. 1), and the difficulties of measuring grain sizes in *solid* rock;

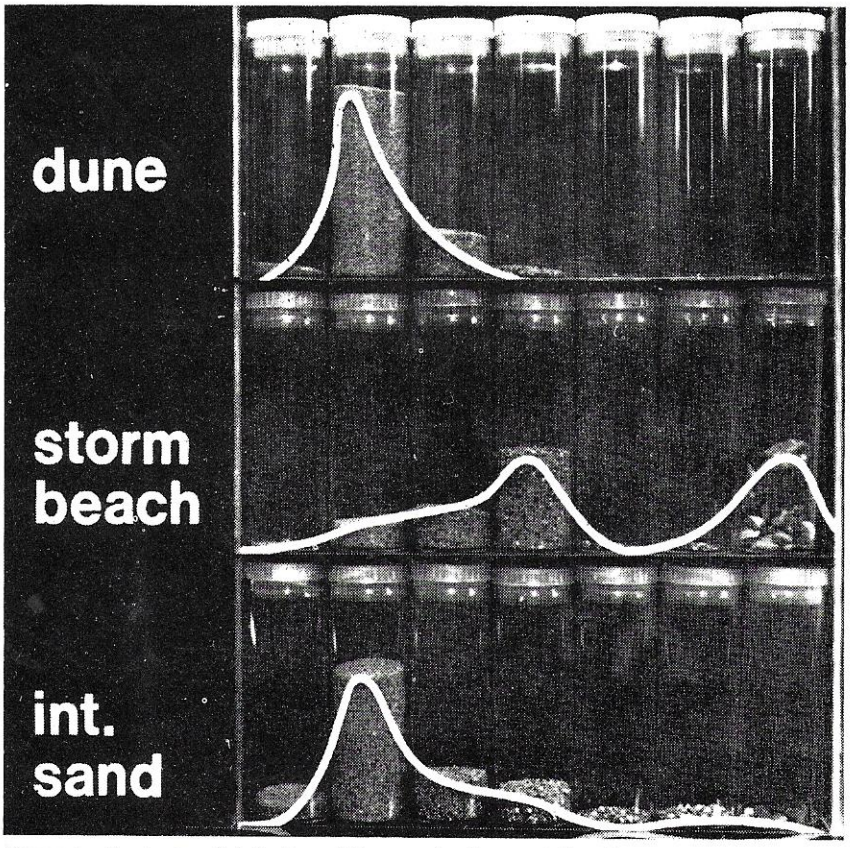
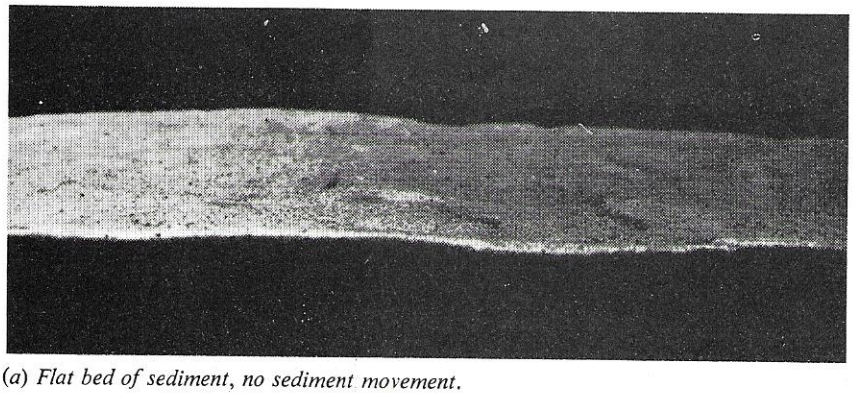


Figure 1 Grain-size distribution of three parts of a coastal environment.

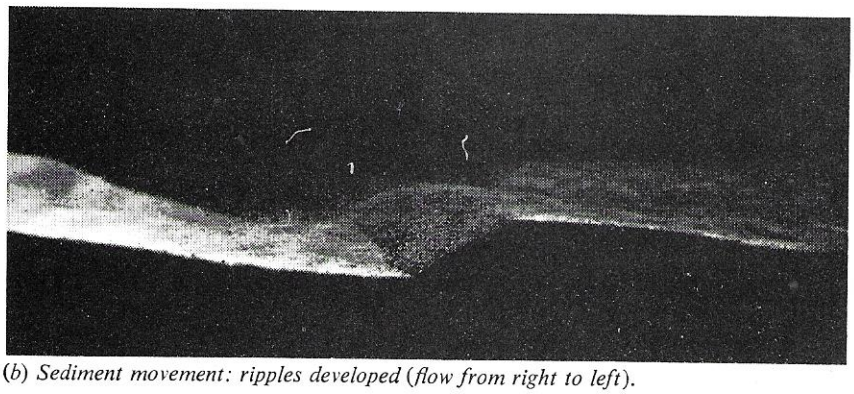
(iii) fossils: evidence for shells having been transported after death, so that remains of organisms that had different life habits are found together;

(iv) ripple marks and their relation to flowing water; examination in the field and laboratory gave a sequence of structures shown in the photos (Fig. 2): in addition, the formation of cross-stratification was also explained;

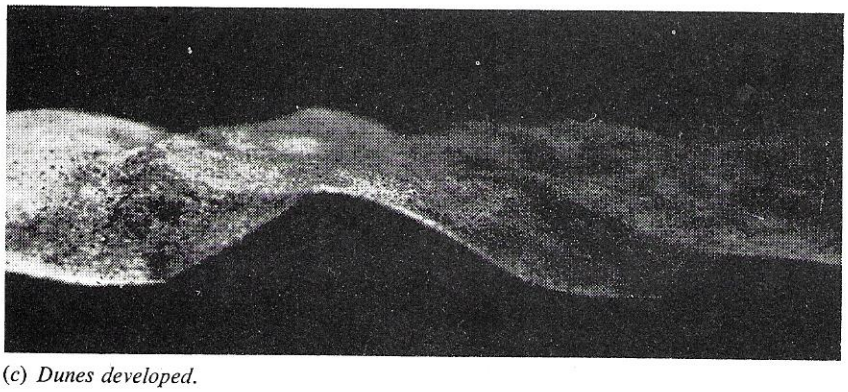
Figure 2 Changing form of bed of sediment in a flume tank as the flow velocity of the water is increased (from (a) to (d)).



(*a*) *Flat bed of sediment, no sediment movement.*



(*b*) *Sediment movement: ripples developed (flow from right to left).*



(*c*) *Dunes developed.*

(*d*) *Flat bed of sediment, with moving 'carpet' of sediment.*

(v) at the end of the programme, Dr Wilson made the point that the coastal environment afforded a number of demonstrations of the present being the key to the past, and that it was also fairly typical of deposition occurring around the North Sea Basin.

After the programme read Appendix 2 of the Main Text, which describes a geological model of this area.

TELEVISION UNIT 27

Pre-broadcast Notes

Subject
Earth History II
A Case Study of the Geological History of the North Antrim Coast
Speakers
Professor I. G. Gass
Dr R. C. L. Wilson

Apart from the TV programme for Unit 26, we have spent very little time talking about geology as a field science.

We hope by now that you are aware of the tremendous progress that has been made in the last decade in unravelling the history of our planet. An earlier radio programme (25) discussed the 'revolution in the Earth sciences', with special reference to sea-floor spreading and plate tectonics. For a change, all that you must read before viewing this programme are these notes, and the Units up to and including the last (Unit 26). If you have read Unit 27, you have probably realized that ideas about the evolution of life and our atmosphere have also suffered a recent 'revolution'. New ideas always receive much attention – but remember new ideas in science arise out of years of painstaking groundwork! And that is what TV 27 is all about. In it, Professor Gass and Dr Wilson look at a small area on the coast of Northern Ireland, and show how its geological history can be deduced largely from investigations carried out in the field. Before viewing, examine Figures 1, 2, 3 (*a*) and (*b*), and Plate A facing p. 80.

Post-broadcast Notes

1 Summary of the programme

Professor Gass introduced the programme, and showed the black basalt capping the white chalk at Ballycastle (locality 3). Dr Wilson then took up the story of the chalk, showing the inclined bedding, and bands of flints at Portrush (locality 7). He then reviewed the evidence concerning the environment of deposition of the chalk, pointing out that it was a very pure calcium carbonate rock – a limestone – formed from a plankton 'bloom' of coccoliths and other microfossils (Fig. 2 (*b*) and (*c*)). Dr Wilson suggested that the composition of the chalk together with fossils found in it (Fig. 2 (*a*)) indicated that it was deposited in a warm, fairly deep sea (perhaps 2–300 m).

Dr Wilson then handed over to Professor Gass who showed that in places the chalk and flints became extremely shattered, and that blocks of basalt occurred in it. From the evidence available in the two localities discussed by Professor Gass, it appears that the lava might have been injected through the chalk and extruded at the surface. However, detailed studies have shown that the lava-filled depression in the chalk in fact represents an original chalk landscape over which the lava flowed. The hollows were

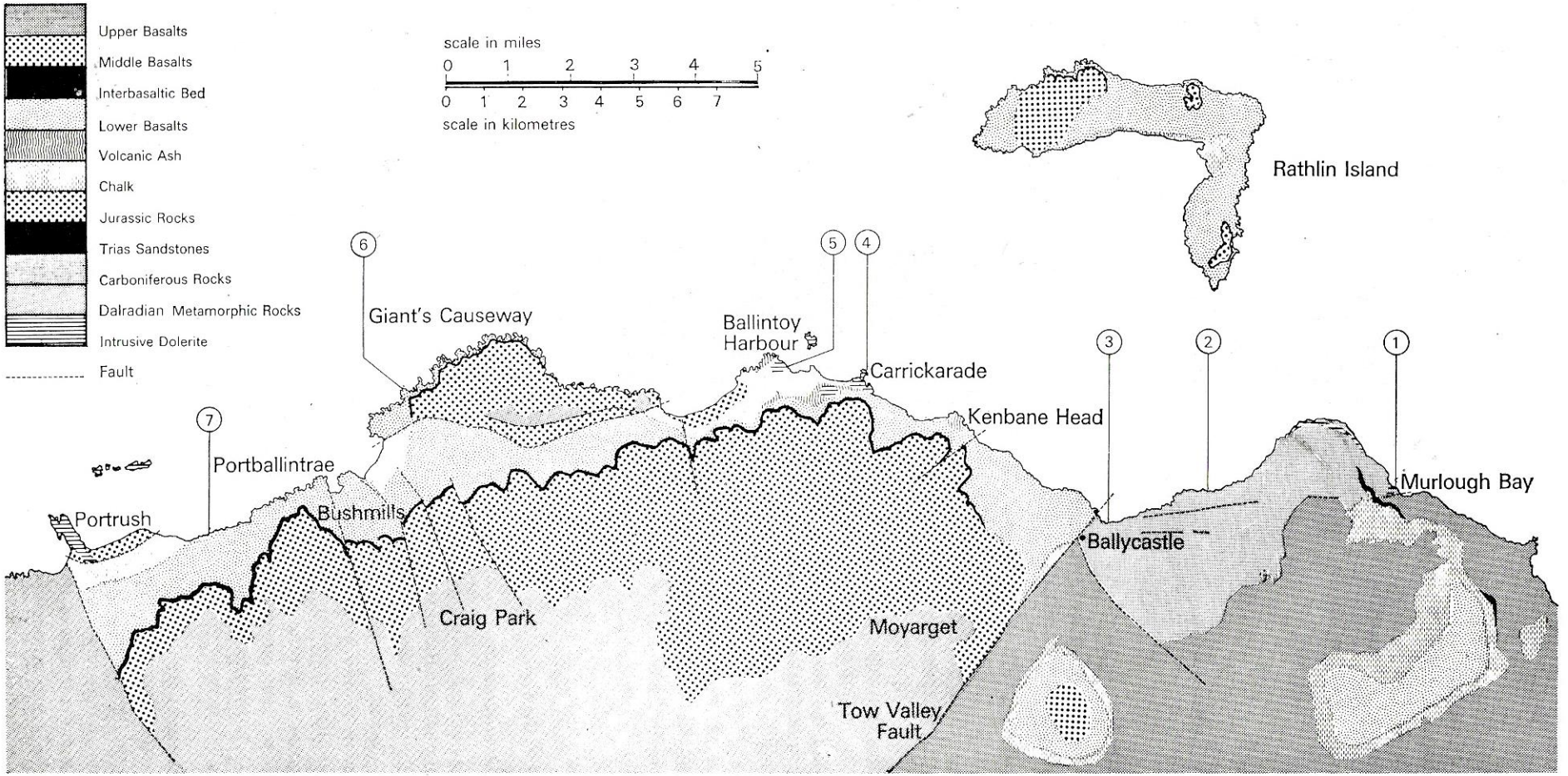
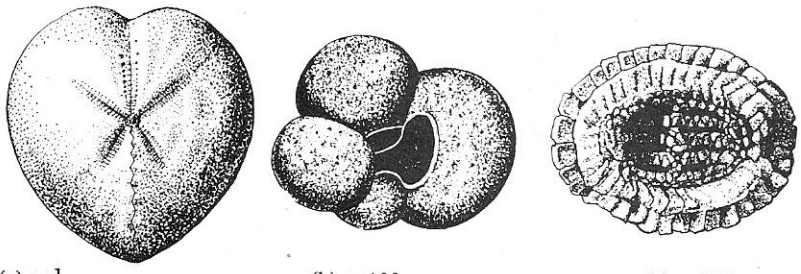


Figure 1 Geological map of the area around Ballycastle, Northern Ireland. During the programme, Professor Gass and Dr Wilson will first visit the coast at Ballycastle locality 3, then Portrush 7, then Ballintoy Harbour 5 and finally Murlough Bay 1. Localities 2, 4 and 6 are shown on Plate A.

Based upon the Geological Survey of Northern Ireland, 1963. Crown Copyright.



(a) $\times\frac{1}{2}$ (b) $\times 100$ (c) $\times 800$

Figure 2 An assemblage of Chalk fossils. From the sketches in Chapter 14 of Understanding the Earth *you should be able to identify these fossils.*

Figure 3 (a) Cliffs at Murlough Bay. Try and sketch in the geological sequence after the programme.

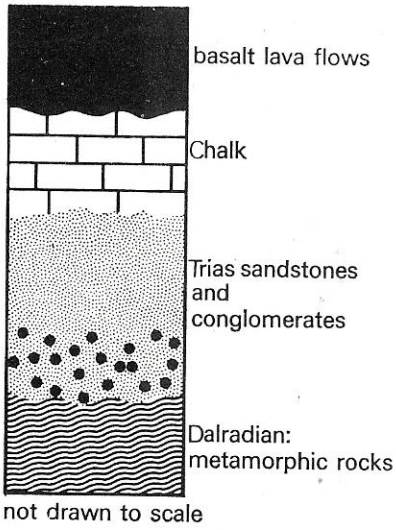


Figure 3 (b) Outline geological succession near Murlough Bay.

filled with water, and as the lava flowed into them, the water was 'flashed' to steam, resulting in explosions which shattered the chalk and the basalt. At Ballintoy Harbour (locality 5), Professor Gass showed a basalt plug (Figs. 5 and 6, Plate A) through which lava must have been extruded. He then quoted the radiometric age of the lavas, which are some 50 Ma old, and discussed how experimental work suggests that they cooled from a temperature of over 1 000 °C.

Professor Gass then showed the extent of the lavas of this age, which are found not only in Antrim, but along the west coast of Scotland where they are over 2 km thick. Lavas of similar type occur in East Greenland (where they are the same age) and also in Iceland, where their age is about 15 Ma. Professor Gass showed that the lavas, and associated volcanic centres, were probably associated with the opening of the North Atlantic some 50-60 Ma ago.

The programme then examined the geological history of the study area prior to the formation of the basalts. A cliff section at Murlough Bay (locality 1) was examined. Here Dr Wilson drew a field sketch, and related the scenery to the underlying geology. He showed that the geological sequence exposed at this locality spanned a period of about 800 Ma, but that the record was far from complete, consisting rather of gaps than a continuous rock record. You should complete Figure 3 (*b*) after the programme.

Dr Wilson showed that the Chalk was underlain by red sandstones which were probably deposited from intermittently flowing rivers in an arid environment. The pebbles at the base of these sandstones could be matched with the underlying metamorphic rock, which was folded and metamorphosed between 400 and 500 Ma ago, whereas the original sediments were laid down as much as 800 Ma ago. Both junctions between the different rock types (Chalk: red sandstone: metamorphic rock) represent considerable time gaps. In conclusion, Dr Wilson outlined the palaeogeography of Britain during the deposition of the Chalk, and during the period when the lavas were being extruded.

2 Geology of your local area

We hope this programme will encourage you to look at local geology. If you wish to find out something about your local geology, there are two series of publications which will help.

(i) British Regional Geology (H.M.S.O.) a series of 17 handbooks describing England, Scotland and Wales. Prices range between 30 and 40p.

(ii) The Geologist's Association Guides: a series of nearly 40 Field Excursion Guides. Obtainable from: 'Scientific Anglian', 30A, St Benedict Street, Norwich, Norfolk. Cost about 20–40p.

Plate A Captions

Figure 1 Photomicrograph of olivine basalt. Large irregular yellow grains are olivine, black and white finer-grained material consists of lath-like crystals of plagioclase. Width of field of view approximately 1 cm.

Figure 2 Sequence of lavas just west of the Giant's Causeway (locality 6). Red layer running parallel to path is weathered top of Lower Lava Series, of which two flows may be seen below the path. Above the weathered horizon occurs the columnar base of the Middle Lava Series.

Figure 3 Fingal's Cave, Isle of Staffa, off NW coast of Island of Mull, W Scotland. The cliffs show basalt columns capped by irregularly jointed basalt. The columns are about 15 m high. Both types of joint pattern were produced during the cooling and contraction of the lavas.

Figure 4 Basalt columns forming the Giant's Causeway (locality 6) on the Antrim Coast. The Middle Lava Series of Antrim also develop the structures shown in Figure 3.

Figure 5 Basalt plug, intruded through Chalk, Ballintoy Harbour (locality 5).

Figure 6 The same plug as in Figure 5, but view from locality to right (west) of Chalk block seen in Figure 5. In the programme, watch out for the change in the appearance of the beach from when this photo was taken. The island is another basalt plug from which the surrounding Chalk has been removed by marine erosion.

Figure 7 View of east side of Carrickarade Island (locality 4). This is another volcanic centre, but instead of being filled with basalt, it contains material produced during a phase of explosive volcanic activity. The large blocks are volcanic bombs composed of basalt, and surrounded by fine-grained volcanic ash. The largest bomb (just up, and left of centre) is 4 m in diameter.

Figure 8 The North Star Dyke (locality 2). A vertical sheet of basaltic rock formed as part of the intrusive activity associated with the extrusion of the Antrim Lavas. On the horizon the cliffs of Rathlin Island can be seen, with black basalt capping white Chalk.

Figure 9 The weathered basalt layer (the Interbasaltic Bed) at locality 6. These structures are known locally as 'giant's eyes'. The red, brown and buff colour of the rock is due to the presence of aluminium and iron oxides which are the end product of intense weathering of basalts during the warm humid climate of the Tertiary period (see TV notes Unit 24). Earlier this century, this layer was mined as an aluminium ore in Northern Ireland, and shipped to Scotland for smelting.

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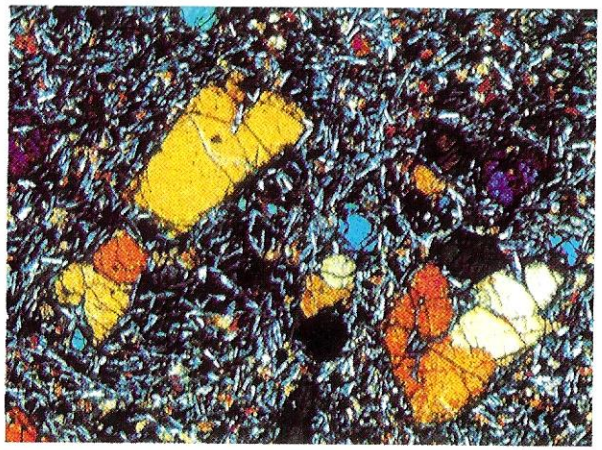

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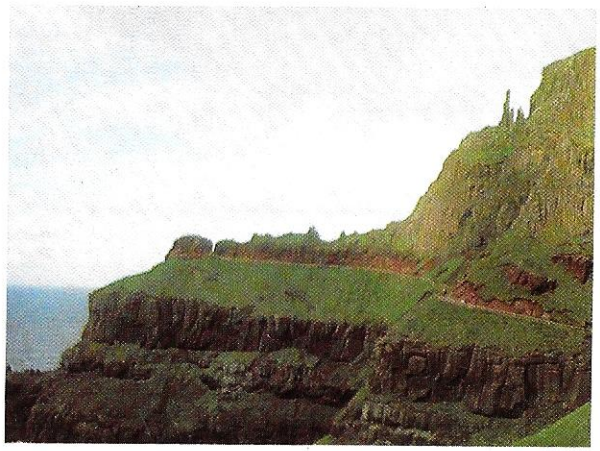

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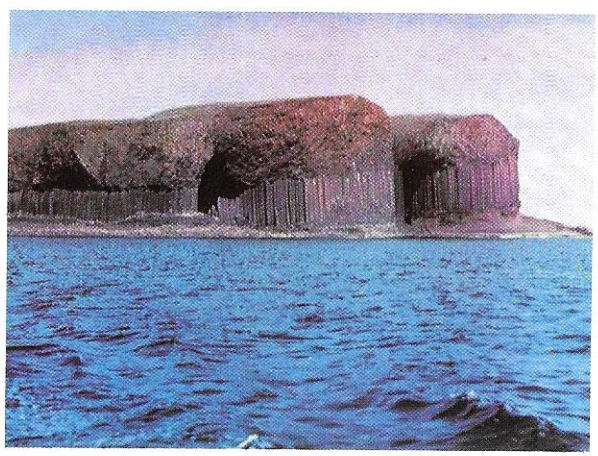

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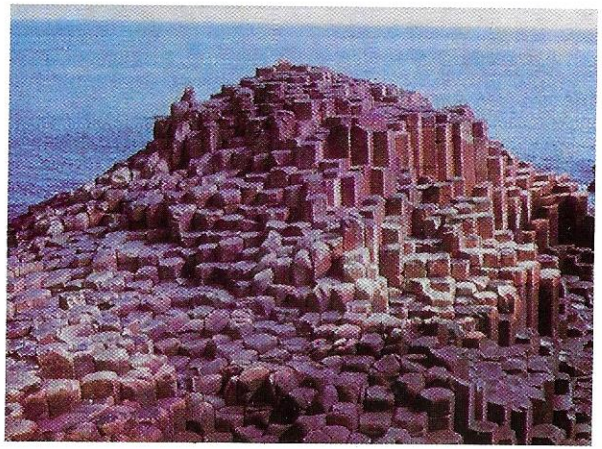

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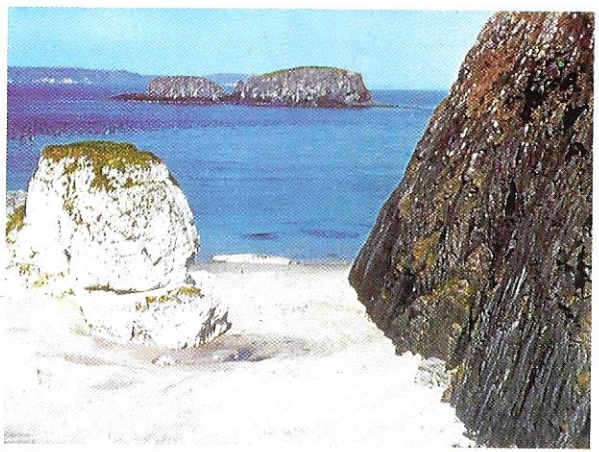

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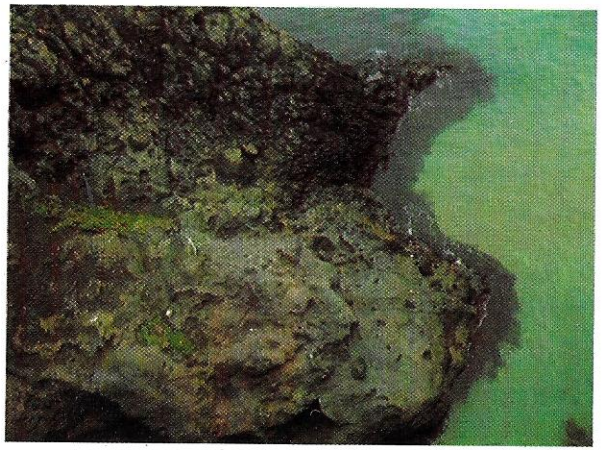

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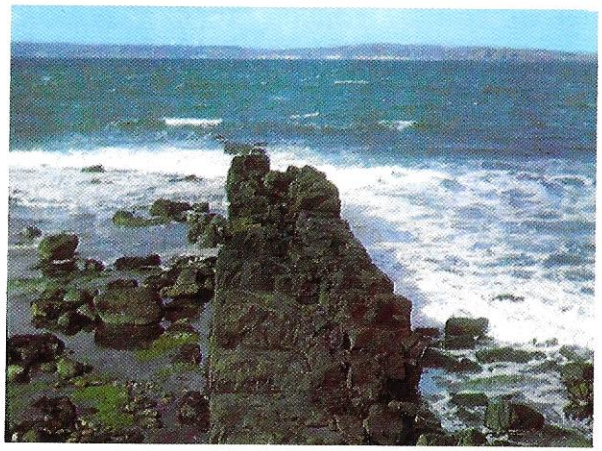

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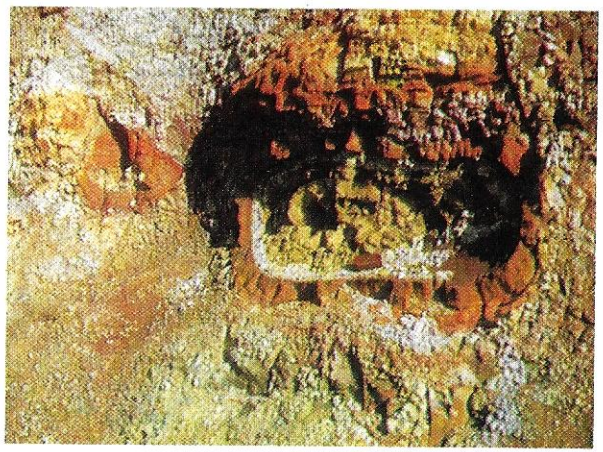


Television Unit 7 Post-broadcast Notes (see p. 24)

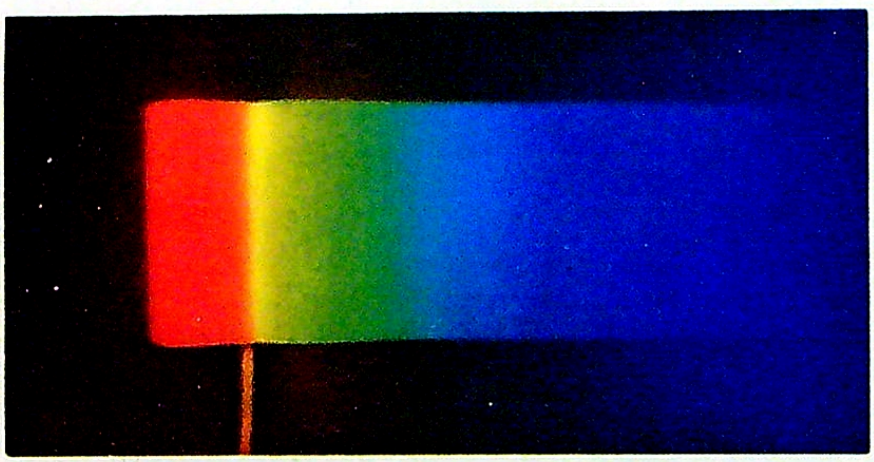


Figure 2 The white light spectrum and the sodium line.

TELEVISION UNIT 28

Pre-broadcast Notes

Subject
Electromagnetic Radiation
Speakers
Professor M. J. Pentz
Professor G. F. Elliott
Professor G. S. Holister

This week's television programme deals with three topics:

1 *Aperture and Resolution*

The ability of a spectrometer to resolve two lines in the mercury spectrum depends on the aperture which limits the width of the light beam.

2 *Diffraction*

We demonstrate light diffraction by various regular structures. Grids are placed in the light path (a laser beam) and the diffraction pattern which they produce is examined. The demonstration is then extended to the determination of molecular structures by X-ray diffraction.

3 *Photo-elasticity*

A polariscope is used to show how the magnitude and direction of mechanical stresses in load-bearing structures can be examined in photo-elastic models with polarized light.

Pre-broadcast Reading

This week, to get the best out of the television programme, you will have to read most of the Main Text. However, the parts of the text dealing directly with the demonstrations are:

1 28.2 and 28.4;

2 28.5;

3 28.9 and Appendix 2.

(Home Experiments E1, E2, E3 are also useful.)

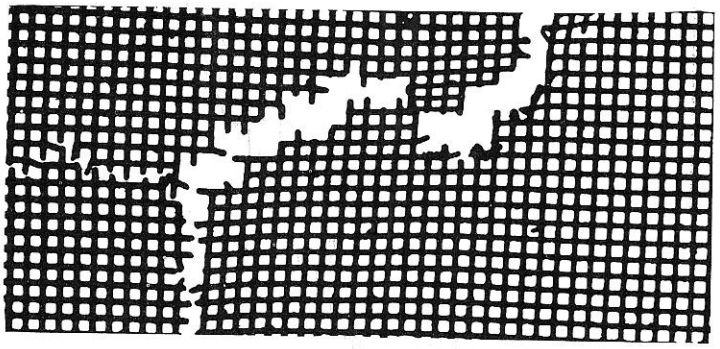
Post-broadcast Notes

The main educational points of the demonstrations are as follows:

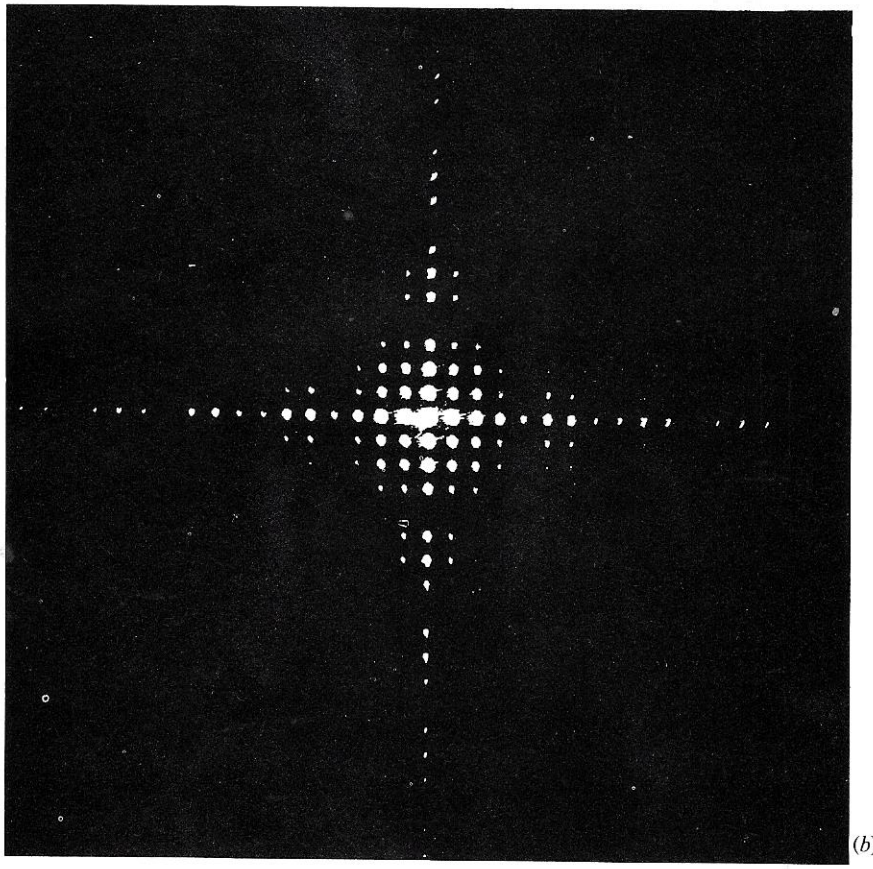
1 The resolution of the spectrometer (as indeed of all optical instruments) depends on the aperture of the resolving system. A smaller aperture decreases the resolution.

2 'Diffraction' patterns produced by the interference of electromagnetic radiation may be used to determine the structure of an object placed in the path of the radiation, if that object has regularities which are comparable with the wavelength of the radiation.

Figures 1–3 (pp. 82, 83) are taken from the television programme and show the relationship between the grid placed in the path of the laser beam and the 'diffraction' pattern (interference pattern) it produces.



(*a*)

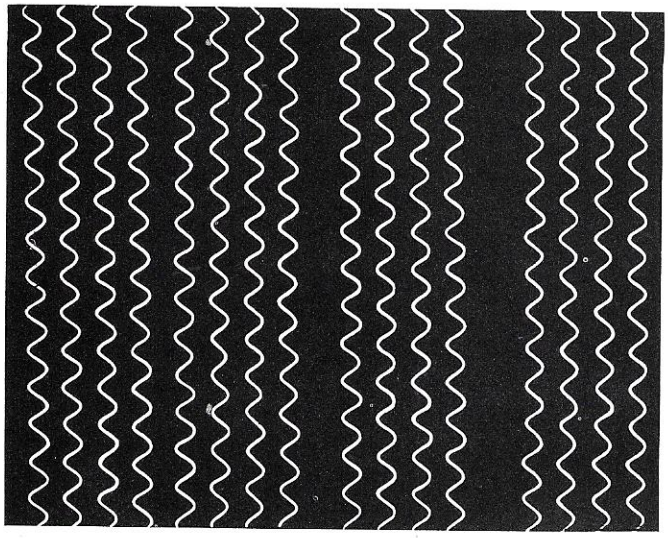


(*b*)

Figure 1 *A regular lattice. (a) The grid, (b) the pattern.*

An important point to note is that a major fault in the first grid has no effect on the diffraction pattern it produces.

(a)



(b)

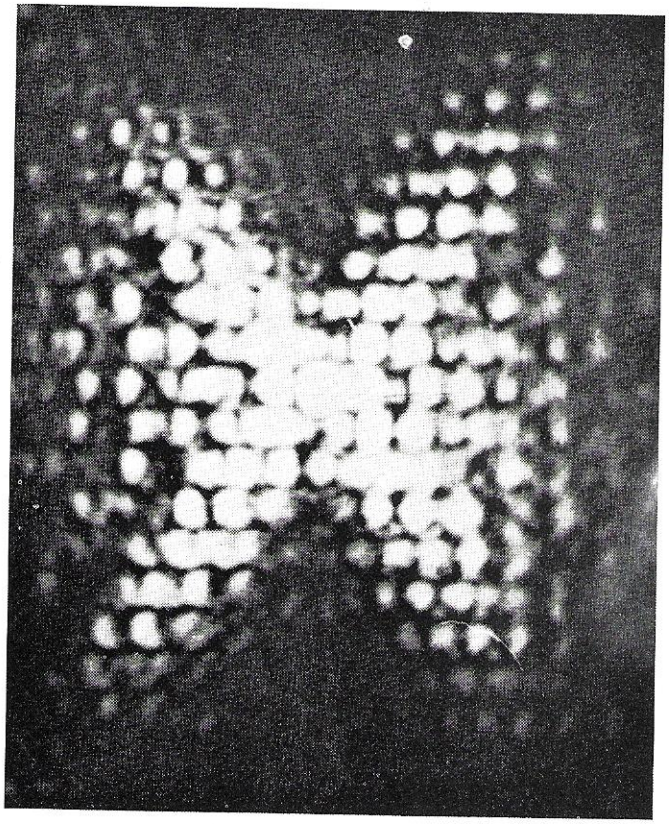
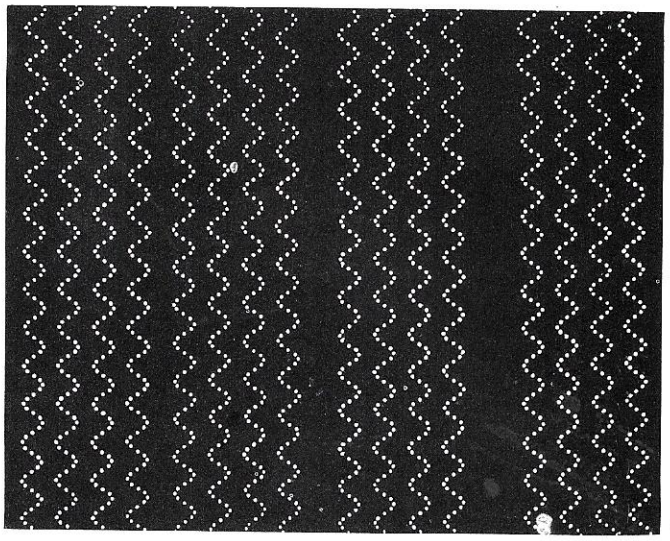
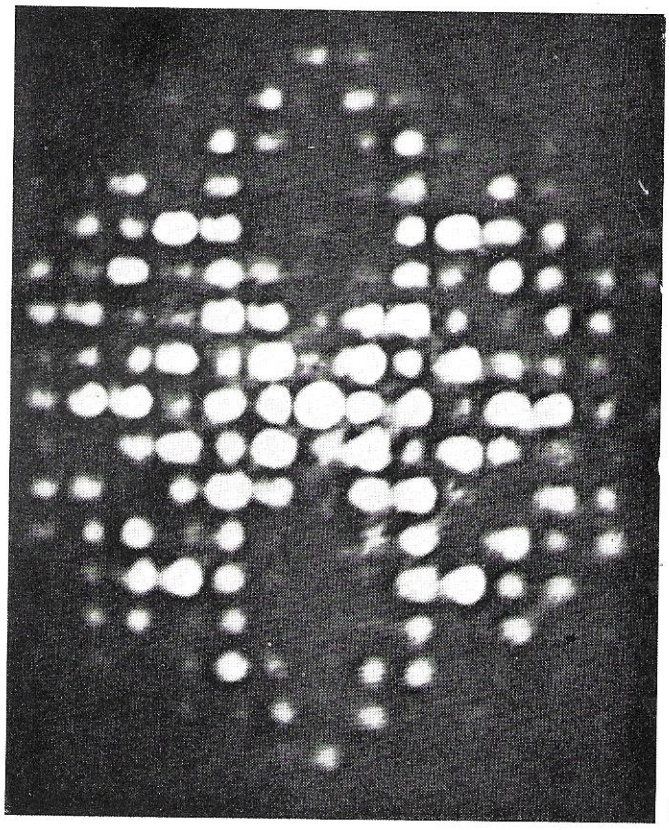


Figure 2 Continuous helices. (a) The grid, (b) the pattern.



(a)



(b)

Figure 3 Points on helices. (a) The grid, (b) the pattern.

Lastly, Figure 4 below compares the diffraction pattern produced by the point-helix grid to the X-ray diffraction pattern produced by the helical DNA molecule. The major similarity, the diamond-shaped clear region above and below the centre, is apparent in both patterns.

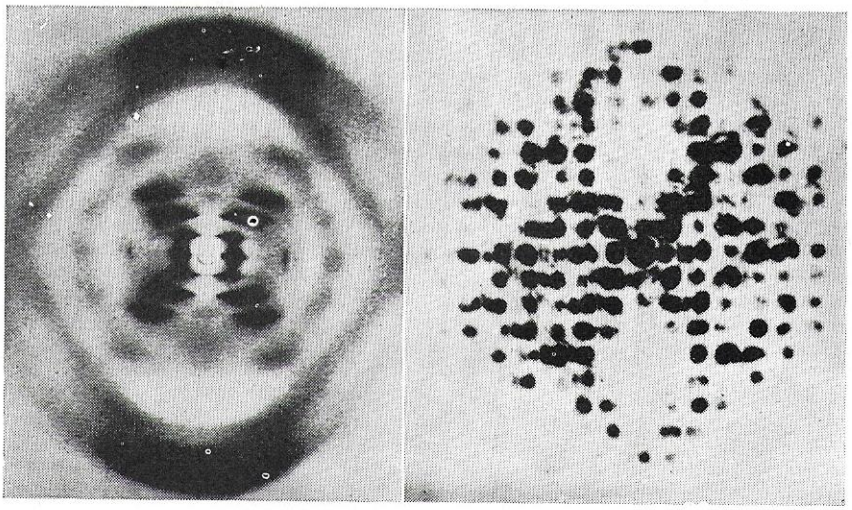


Figure 4

3 (i) The coloured isochromatic fringes remain stationary when the analyser is rotated. These fringes give the magnitude of the stress at any point just as contour lines give the height above sea level of a point on a map.

(ii) The black isoclinic fringes move when the analyser is rotated. These fringes are used to find the direction in which the stress is acting at a particular point.

(iii) Photo-elastic materials are used in stress analysis in two main ways:

A solid model of the component of interest can be stressed under laboratory conditions (e.g., the crane hook).

A coating which is stuck on to an actual component with reflective cement can be stressed under actual working conditions (e.g., the aircraft undercarriage).

An exercise using a diffraction pattern from paragraph (2), above

This exercise is purely optional, for you to do if you are interested.

(i) Measure the distance between the successive maxima in the horizontal direction in Figure 1 (*b*). This is the original size, taken with a distance of 0.25 m between the grid and the photographic plate. The wavelength of the laser light was 6.3×10^{-7}m. Use the relationship which is derived in paragraph (4) of Home Experiment C to calculate the spacing of the holes on the grid.

(ii) Look at the diffraction pattern (Fig. 1*b*) and, counting out from the centre along the horizontal direction, observe which maximum* is weak in intensity compared with the others. Then measure on the grid-photograph (Fig. 1*a*) the ratio between the spacing of the holes and the width of the dark parts of the grid. If this ratio is n:1 then the nth maximum should be weak. Is this the case? (Of course, the ratio n:1 may not be a whole-number ratio, but you only have whole-number maxima in the diffraction pattern.)

* *The first, second, third or so on, with the centre as zero.*

TELEVISION UNIT 29

Subject
Quantum Theory
Speakers
Professor M. J. Pentz
Professor F. R. Stannard

Pre-broadcast Notes

The programme is almost entirely devoted to the experimental evidence upon which quantum theory is based.

Professor Pentz begins with a demonstration of the pressure of light. A gold foil (4μm* thick) is suspended from a long, exceedingly fine (3 μm diameter), quartz fibre. It is contained in a highly evacuated glass vessel (Fig. 1). By repeatedly directing a beam of light on to one part of the foil, he sets the foil oscillating—rather in the same way as one sets a child's swing in motion by giving pushes at the right moments. (Incidentally, the toy illustrated in Figure 2, which you may have seen in operation, does *not* demonstrate the pressure of light. Certainly it is set rotating by the action of shining a light upon it, but this motion is due to thermal convection currents in the residual air inside the partially evacuated glass bulb. A true demonstration of the pressure of light, like the one shown in this programme, is in fact quite tricky to set up.)

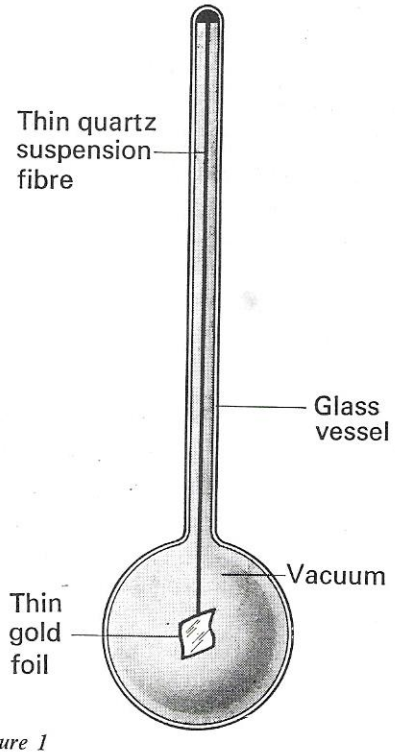


Figure 1

Professor Pentz next takes a qualitative look at the photo-electric effect. This is followed by an experiment in which Dr** Stannard sets out to measure Planck's constant, *h*, and to investigate how the maximum energy of the emitted photo-electrons depends upon the wavelength of the incident radiation. The source of light is a mercury lamp and the individual spectral lines are separated by a spectrometer. Monochromatic light is shone on to a metal disc, A (Fig. 3). Photo-electrons are ejected at the wire ring electrode B, and this flow of electrons constitutes our measured photocurrent. A voltage difference (called a 'bias' voltage) is established between A and B and this has the effect of turning back the

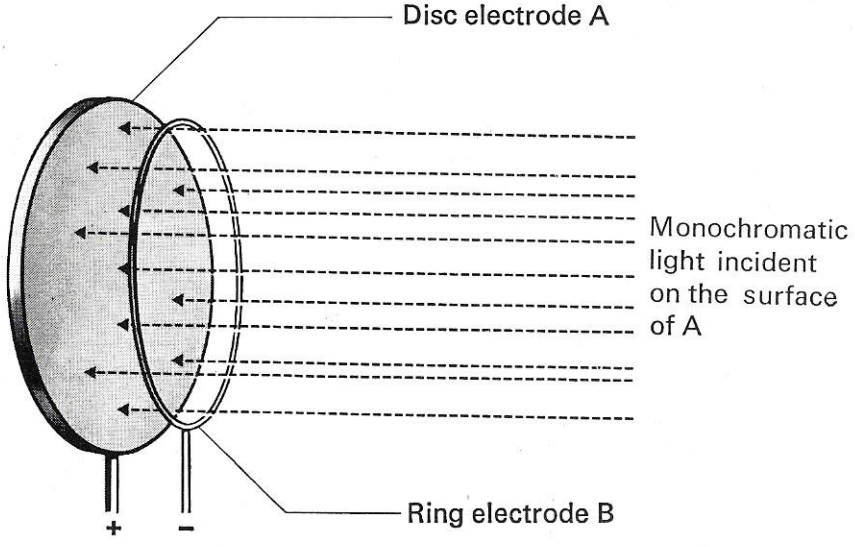


Figure 3

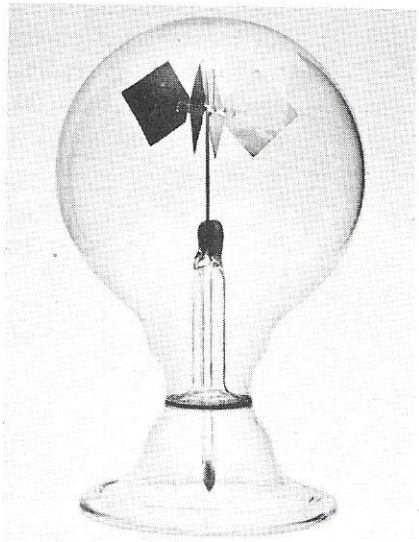


Figure 2

less energetic electrons (Fig. 4). As the voltage is increased, a larger proportion of electrons is turned back and the measured current drops further. Eventually the voltage is just sufficient to turn back even the most

Figure 4 is on p. 86

*micrometres

** *Now Professor.*

energetic electrons and the current drops to zero. This cut-off voltage, V, is therefore a measure of the maximum energy of the electrons ($\frac{1}{2}mv^2_{max}$) appropriate to the particular wavelength being used:

$$\tfrac{1}{2}mv^2_{max} = eV$$

We only have time in the programme to show you one value of a cut-off voltage being obtained; voltages corresponding to other wavelengths were measured earlier in exactly the same way, and are being supplied to you for assessment.

Having dealt with the interaction behaviour of photons, we move on to consider diffraction. This is demonstrated for light using first a piece of gauze, then two superimposed ruled gratings at right-angles to each other.

The diffraction of electrons is then demonstrated in two distinct ways, these being similar to the two ways in which electron diffraction was simultaneously discovered by Davisson and Germer in U.S.A. and by G. P. Thomson in Britain in 1927. In a film of some historic interest, Dr Germer himself demonstrates electron diffraction by reflection at a crystal surface (as in Fig. 2, Main Text). Then Dr Stannard demonstrates the Thomson method of diffracting high energy electrons by passing them through a thin metal foil.

During the programme you will be required to take a reading, so make sure you have a pencil and notebook handy.

When you watch the diffraction rings as Dr Stannard changes the voltage, it will help you to see the effect he is demonstrating if you focus your attention on a particular ring and try to ignore the change in brightness in all the rings.

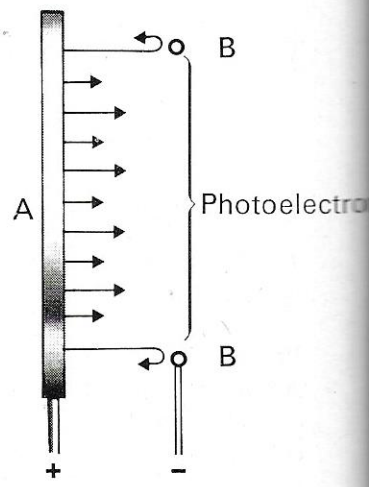


Figure 4

Post-broadcast Notes

There are three things for you to do as a result of this programme.

(i) First we want you to determine Planck's constant, h. The mercury spectrum has five dominant lines in the visible range. These are shone upon a photocell, one at a time, and the retarding voltage necessary for reducing the photocurrent to zero is determined for each. You took one of the readings yourself in the programme. The other four readings have been taken by one of your fellow students who set up the apparatus and recorded the following values:

Wavelength 10^{-6}m	Cut-off Voltage V
0.578	
0.546	0.67
0.492	0.91
0.436	1.25
0.405	1.43

The reading you took in the TV programme corresponded to the wavelength 0.578×10^{-6}m; include your value in the table.

Plot the voltage V against the frequency of the radiation. Use your graph to calculate the value of Planck's constant, h.

(The velocity of light is $c = 3 \times 10^8 ms^{-1}$, and 1 eV $= 1.6 \times 10^{-19}$J.)

(ii) In Figure 5, you are provided with six photographs of electron diffraction patterns. They were obtained with the instrument you

Figure 5 is on pp. 88–90.

saw demonstrated by Dr Stannard towards the end of the programme. The experimental arrangement is shown schematically in Figure 6.

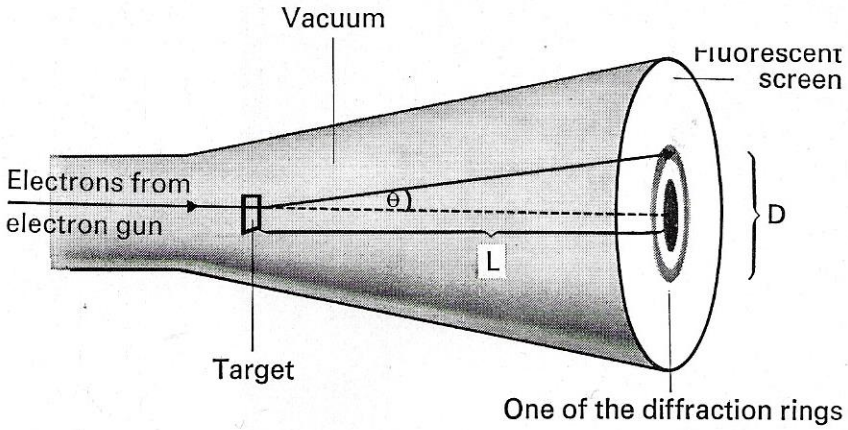


Figure 6

Each bright ring on the fluorescent screen represents a region of constructive interference. Its diameter, D, is proportional to the distance, L, between the screen and the target, and also to the angle of diffraction, θ:

$$\text{i.e. } D \propto L.\theta$$

The angle θ in its turn is proportional to the wavelength of the electron beam, λ, and inversely proportional to the separation of the atoms, d, in the crystalline structure of the target:

$$\text{i.e. } \theta \propto \lambda/d$$

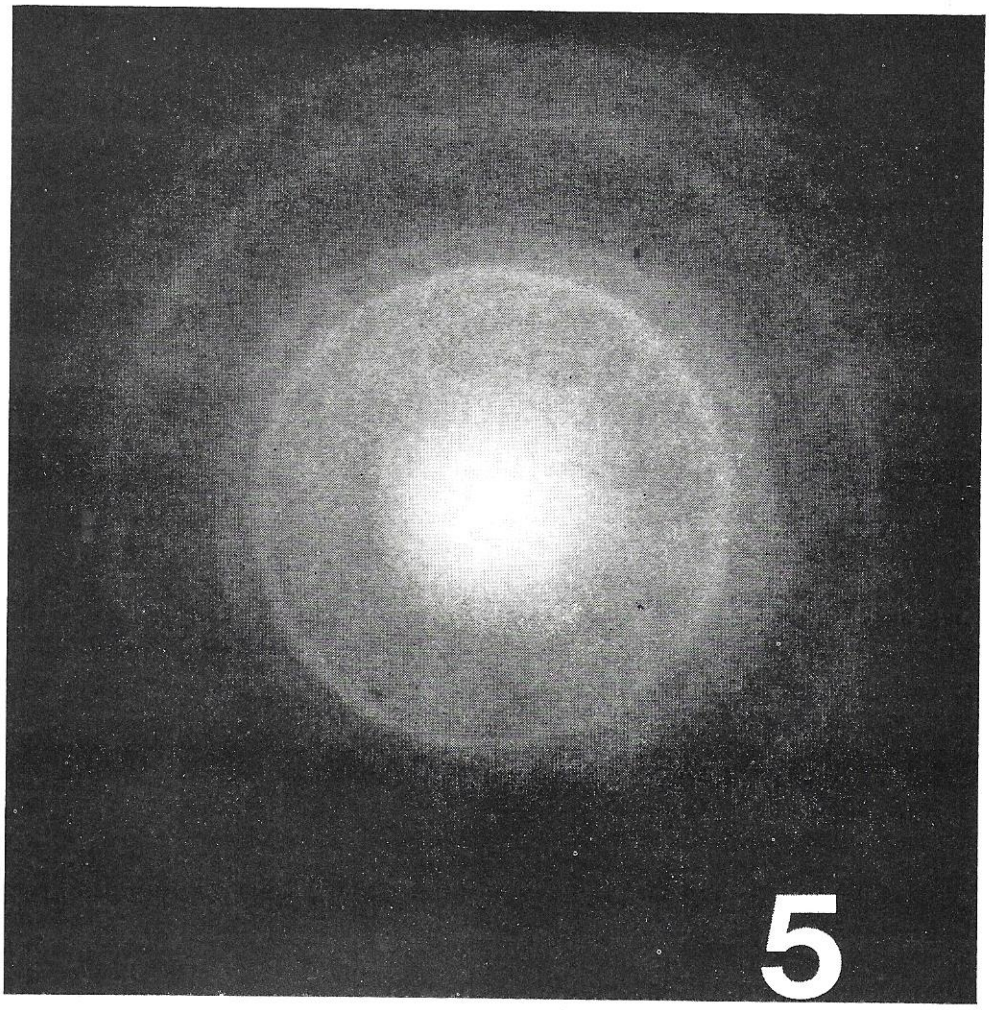
(This comes from equation 1 of the Main Text on the assumption that θ is small.)
Therefore:

$$D \propto \frac{L\lambda}{d} \quad . \quad . \quad . \quad (1)$$

The diffraction pattern is quite a complicated one. However, all you need to note from the photograph is that the pattern, while retaining the same form, *alters in size* as the accelerating voltage is increased in 1 kV steps from 5 kV to 10 kV. Because L and d in equation 1 above remain constant, the relative change in the diameter of any given ring is a measure of the relative change in λ.

We should like you to pick a particular ring in the diffraction pattern which you can identify in each of the photographs. Make measurements of the diameter of this ring on each photograph and plot a graph of this diameter against the inverse square root of the corresponding voltage ($V^{-\frac{1}{2}}$).

(iii) The experiments you have seen demonstrated form the basis upon which quantum theory has been built. At the very end of the programme, we go to the other extreme and take a look at one of the consequences of quantum theory. We pose a philosophical question. You are reminded of this in *SAQ* 11 to which you should now turn (Main Text, p. 66).



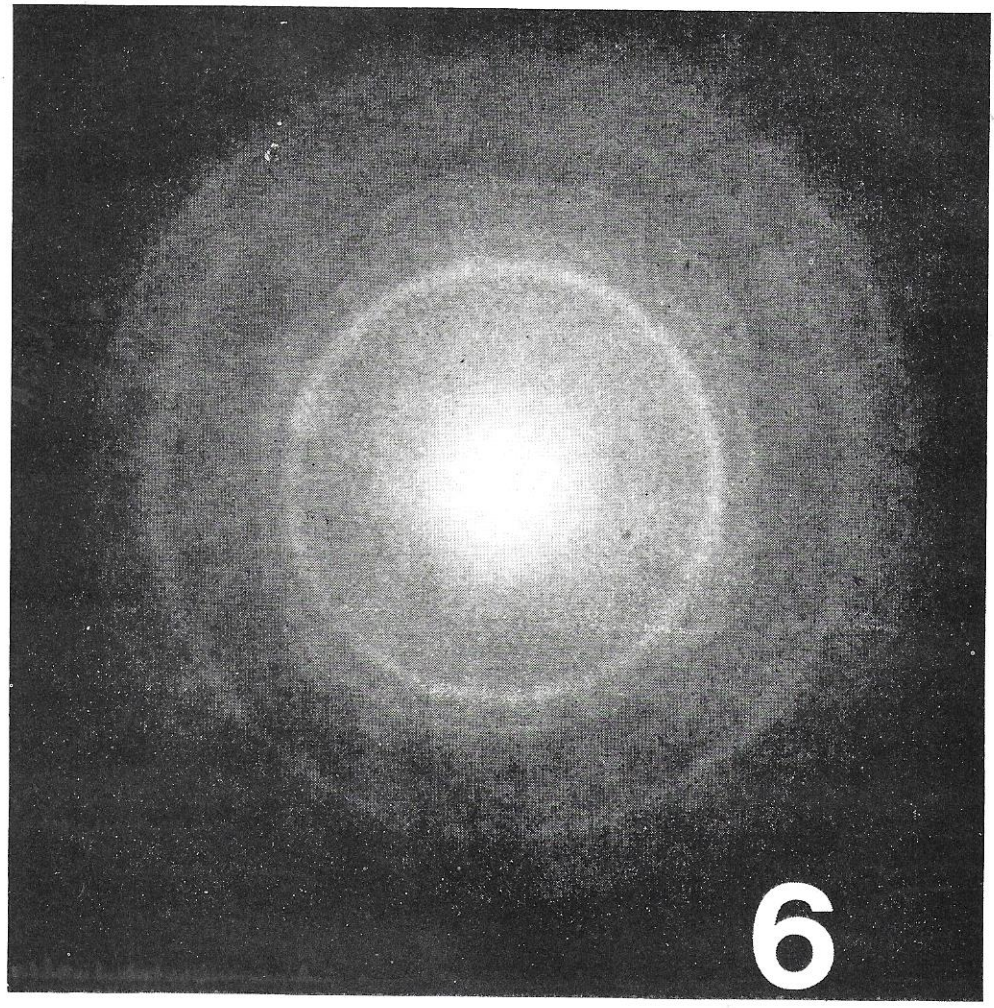
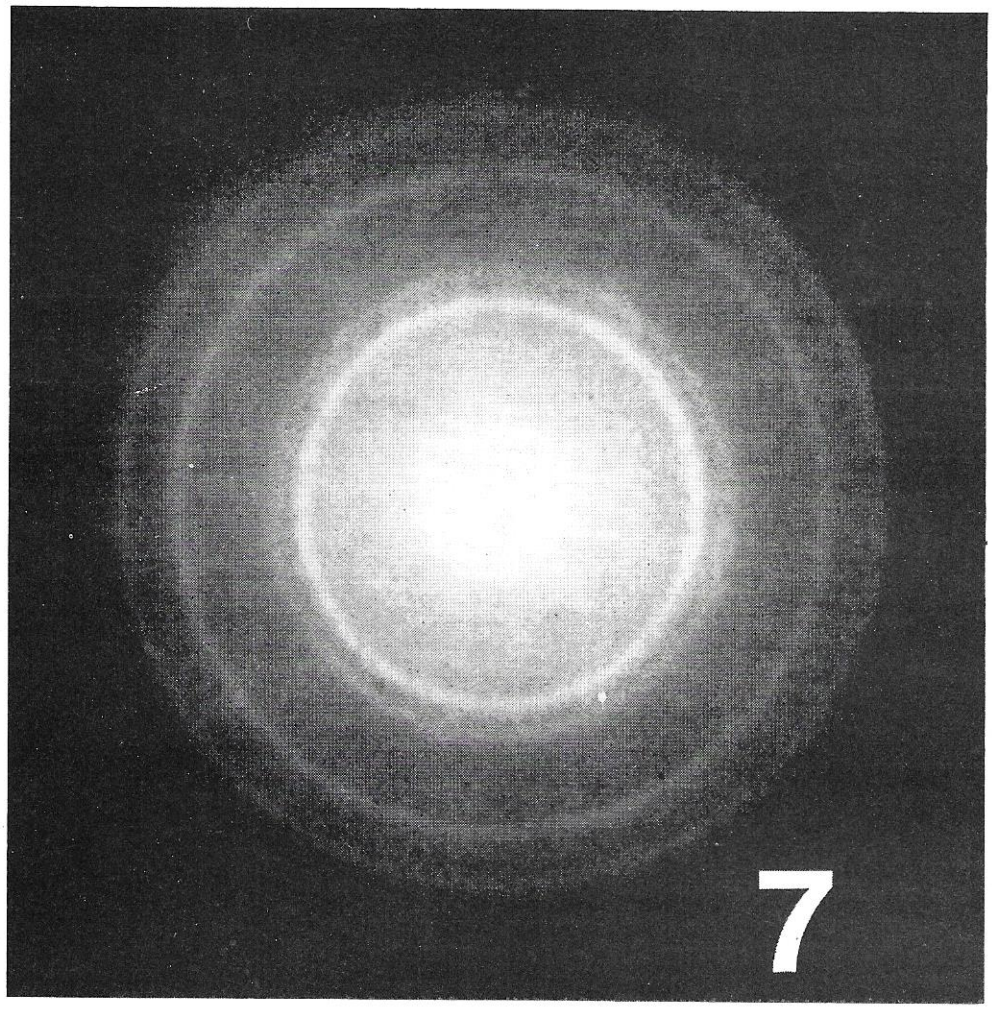


Figure 5



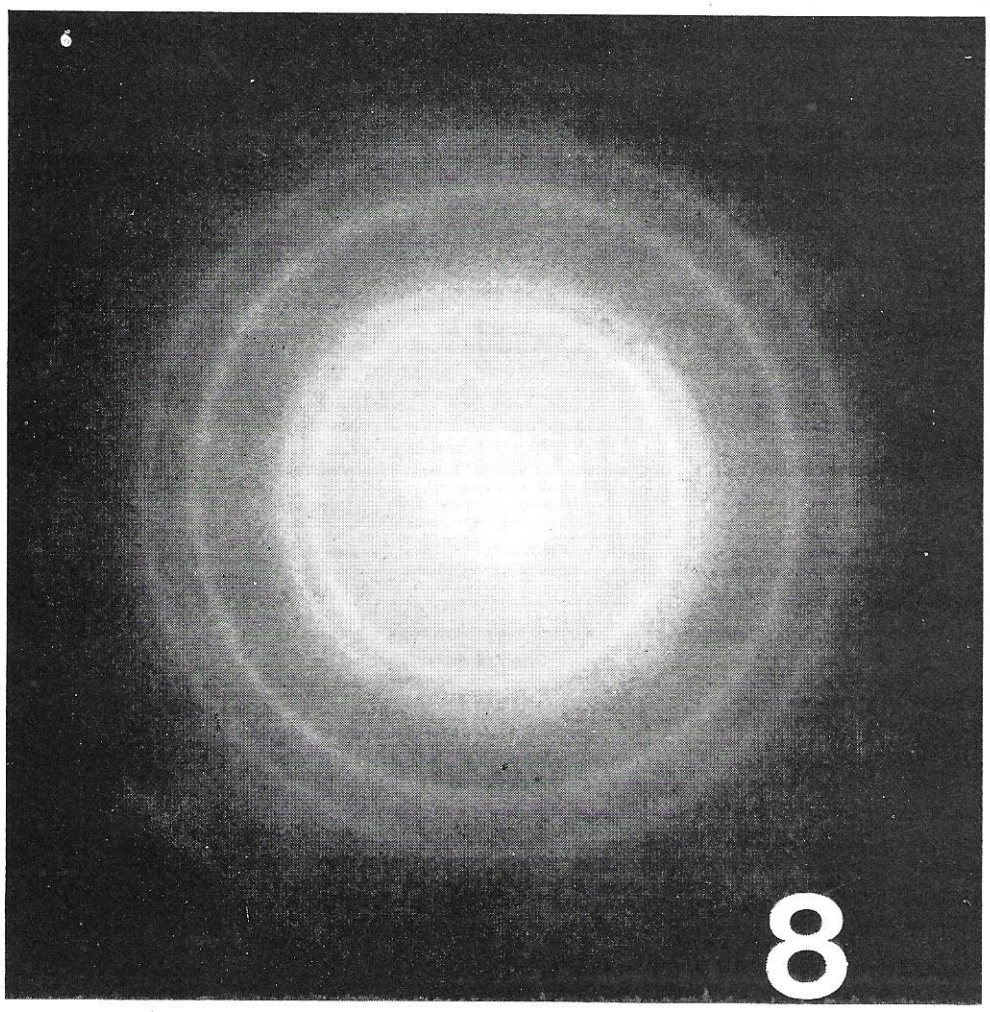
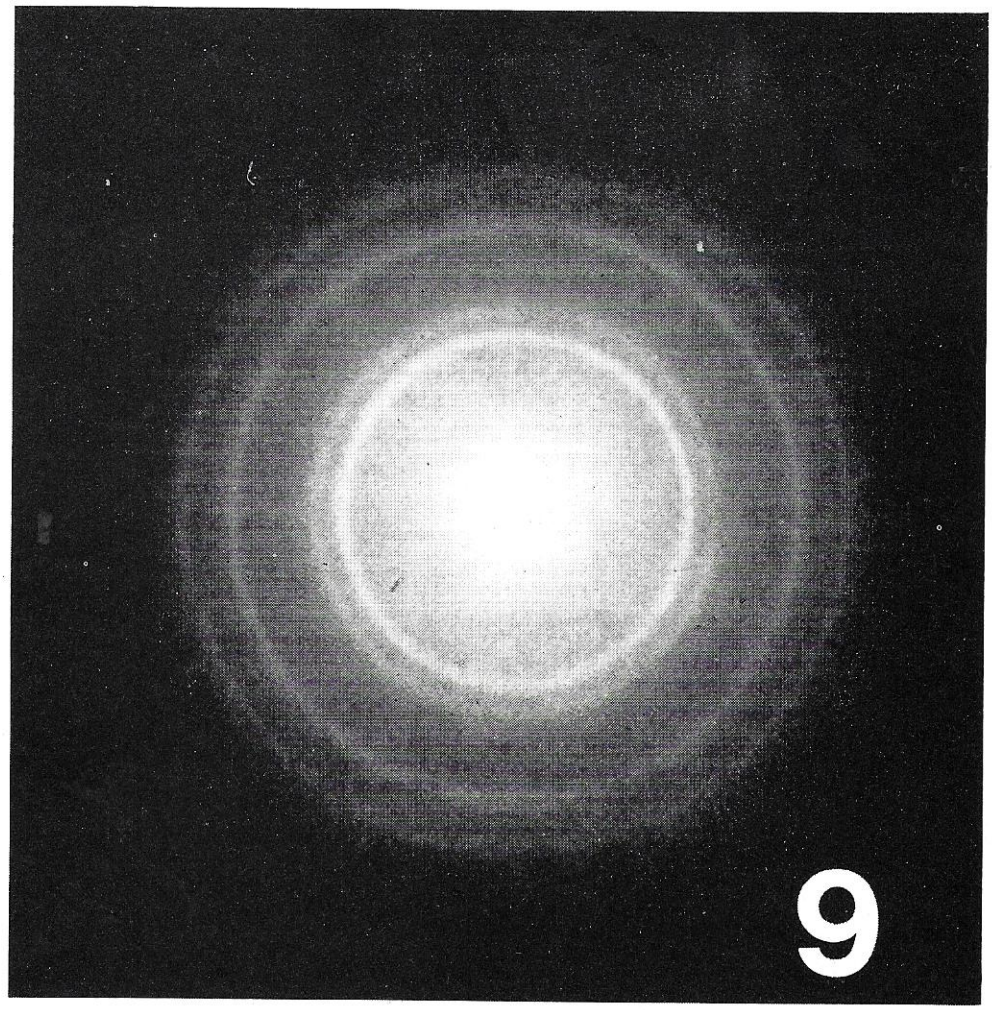


Figure 5 (*contd.*)



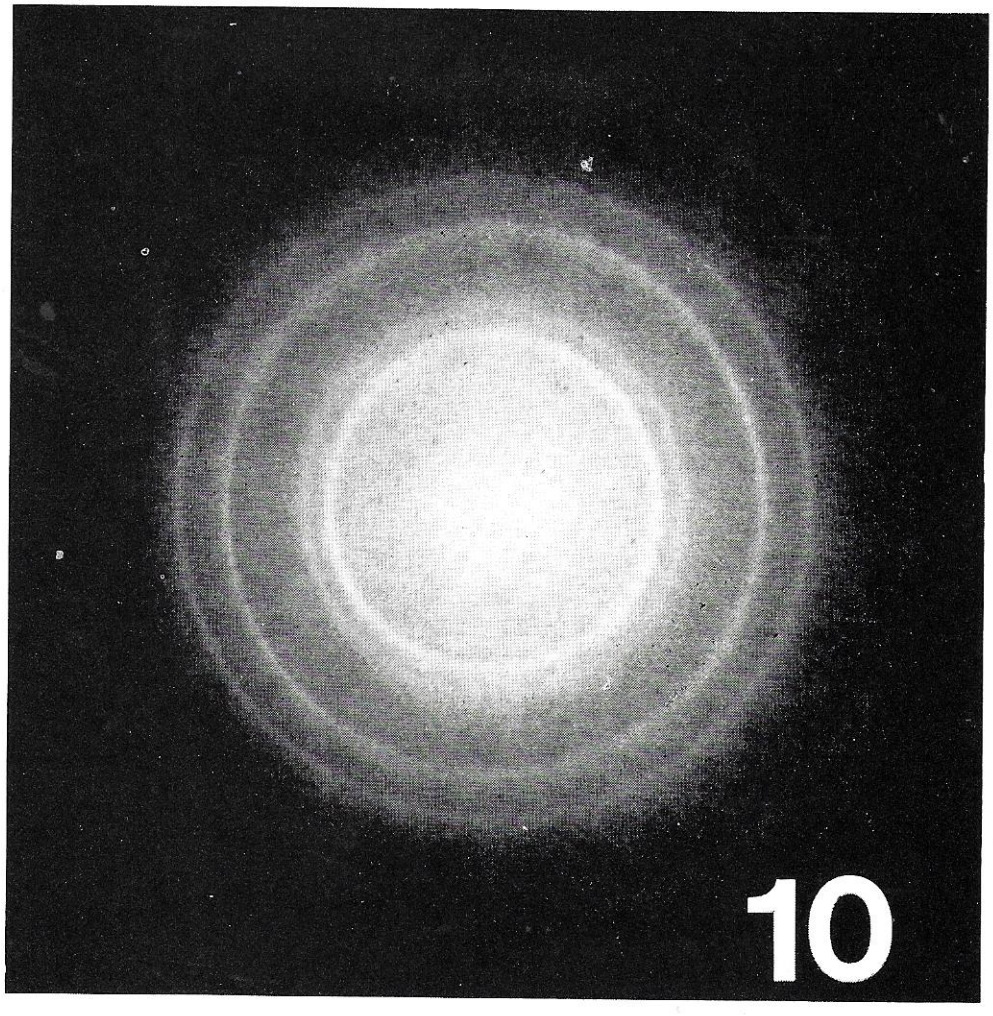


Figure 5 (*contd.*)

TELEVISION UNIT 30

Pre-broadcast Notes

Subjects

1 *Normal modes of a vibrating string.*
2 *Measurement of velocity of ultrasonic waves in a liquid.*
3 *Normal modes of a circular membrane.*
4 *Energy quantization in a mercury atom (Franck-Hertz experiment).*
5 *Home Experiment with a piano.*

Speakers

Professor M. J. Pentz
Dr A. J. Walton
Mr G. C. Fletcher (Visiting Fellow in Physics)

The first part of the programme is concerned with stationary waves and normal modes in a variety of different situations. The frequencies of the normal modes of a string and a circular membrane are measured, and a method of measuring the velocity of ultrasonic waves in a liquid by using stationary waves is discussed. You should read carefully the following Sections in advance of seeing the programme.

Unit 28 Section 28.5.
Unit 30 Sections 30.2.1 (especially Figs. 4 and 5), 30.3.1, 30.3.2 (especially Figs. 11 and 12).

You should also if possible, attempt Home Experiment 1 before the programme.

Measurement of the velocity of ultrasonic waves in a liquid

You will not need to copy down any readings during the programme but you may find a pencil and paper useful for quick notes. The experiment measures the velocity of ultrasonic (high-frequency sound) waves by setting up a stationary sound wave in the liquid (carbon tetrachloride) and using this stationary wave as a diffraction grating (Unit 28, Section 28.6). This technique will almost certainly be new to you. A sound wave is a pressure wave, and in a stationary sound wave at any instant the pressure will vary in a regular manner along the wave with certain points at a higher than average pressure and others at a lower than average pressure. The shortest distance between two points of maximum pressure is *one wavelength*. Half a cycle later, the nodes will still be in the same place, but the points of maximum pressure will have changed to points of minimum pressure (i.e., a maximum amount *below* the average pressure in the liquid) and minima will have become maxima. However, the shortest distance between points of maximum pressure (antinodes) will still be one wavelength—there is, of course, another antinode in between them, but the pressure there will be below the average value. If you are not clear about this, look at Figure 5 in Unit 30 (the two lowest diagrams).

The variation of pressure in the liquid causes minute density variations which affect the speed of light through the liquid. Although this is not quite the same as the diffraction grating described in Unit 28, you should find it quite reasonable that a variation of optical properties in a liquid, with points of maximum density occurring at regular intervals, *might* act as a diffraction grating. The 'lines' of this diffraction grating will be spaced *one wavelength* apart and any experiment which can determine this is determining the wavelength and hence the velocity of the ultrasonic wave.

Franck-Hertz Experiment

In the second part of the programme an experiment is performed which demonstrates how atoms respond when energy is 'fed in' from outside. Just like a string, a membrane, or a liquid, so it will be shown that atoms only absorb energy when that energy has certain well-defined values. In the case of the string, the membrane, and the liquid, the variable energy is fed in by adjusting the frequency of a mechanical vibrator. In the case of atoms the variable energy is fed in by adjusting the kinetic energy of

electrons which are made to collide with the atoms; if the atoms do not absorb energy the electrons will rebound without loss of energy; if they absorb energy the electrons will lose all or part of their energy. This experiment examines the behaviour of electrons after they have collided with atoms. It was first performed in 1914 by F. Franck and G. Hertz. (They subsequently won a Nobel prize for the work.) The experiment to be performed on television is essentially theirs; like Franck-Hertz's it too will try to excite mercury atoms.

Mercury vapour is contained in an otherwise evacuated glass tube (Fig. 1). The electrons are produced from an electrically-heated filament —the cathode. These electrons are then accelerated by applying a suitable voltage V between the cathode and the grid. When V is changed the kinetic energy of the electrons arriving in the plane of the grid is changed. Being an open structure most of the electrons might be expected to pass through the grid to the collector plate, and then flow back to the filament as a current I, measured on a suitable meter. However, there is a reverse voltage (or retarding potential) of 1V applied between the grid and the collector so only electrons with an energy in excess of 1V can reach the plate, the others will be collected by the grid and so by-pass the meter. For example, electrons passing through the grid with an energy of 1.1 eV will be recorded as a current I— those with an energy of 0.8 eV cannot reach the plate and will return to be collected by the grid and therefore will not be recorded.

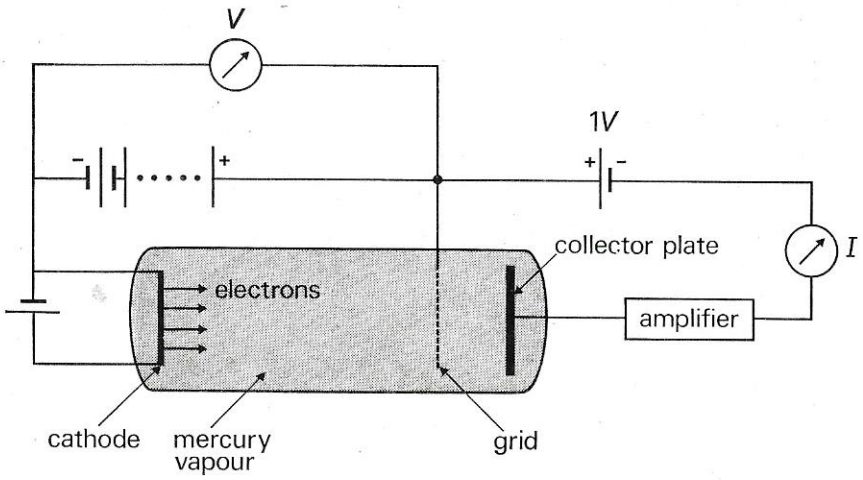


Figure 1

Let us consider the fate of electrons leaving the cathode and being accelerated up by a voltage V, greater than 1V, applied to the grid. Assuming the electrons reach the grid region without having given up any energy *en route* then they will, of course, proceed to the collector and be recorded. If, however, the mercury atoms can absorb the kinetic energy of magnitude V electron volts, then these electrons will be unable to reach the collector and will flow instead to the grid and so not be recorded. In other words the grid acts as a 'policeman'. Those electrons which have not given up energy to the mercury atoms—and which therefore have failed to 'excite' the atoms—are allowed to proceed. Those that have given up all their energy are halted. In essence the experiment simply studies how the number of 'well-behaved' electrons getting through (those making elastic collisions in which no energy is given up to the mercury atoms) depends on their energy (the cathode-grid voltage).

Post-broadcast Notes

1 Ultrasonic Waves Experiment

Figure 2 shows, somewhat schematically, how the interference pattern is produced on the screen as monochromatic light is diffracted by successive density maxima in the liquid. The separation between adjacent 'lines' in the the liquid is the wavelength, L, of ultrasound in the liquid. The position of the first maximum on the screen will be such that light travelling along BC will travel one wavelength further than light travelling along DC, i.e., $BE=\lambda$, where λ is the wavelength of the light used: when this is so, light diffracted from B and D will both arrive in place at C, producing a diffraction maximum at C.

Since triangles ABC and BED are similar:

$$\frac{AC}{CB}=\frac{BE}{BD}$$

i.e.
$$AC=\frac{BE}{BD}\ CB$$

Now, as you saw in practice the spacing of the diffraction maxima is very much less than the screen-to-cell separation D, i.e., CB is effectively D. Also $BE=\lambda$, and BD='line' separation L in the liquid.

i.e.
$$AC=\frac{\lambda}{L}\ D \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The value of L, the wavelength of ultrasound in the liquid, can therefore be determined.

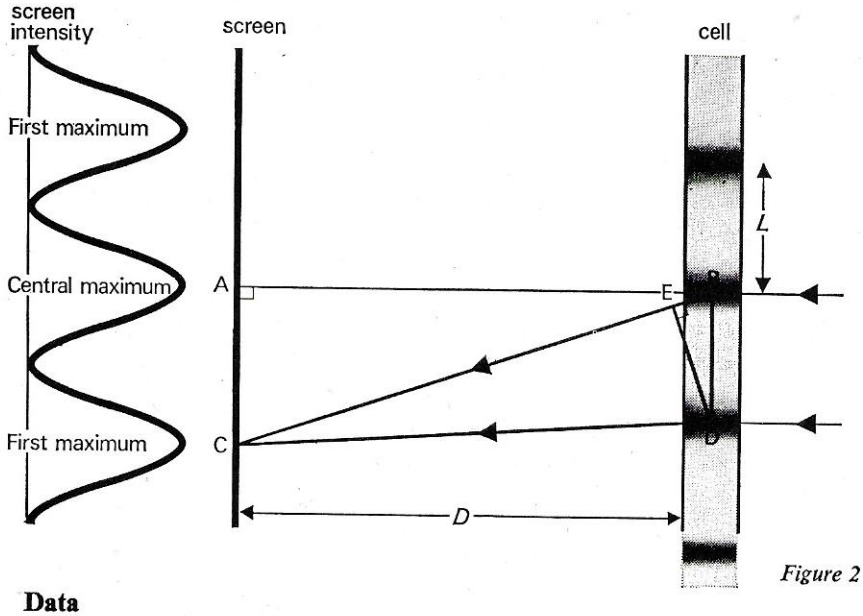


Figure 2

Data

The following quantities were measured in the experiment:

Distance from cell to screen (D)=5.1 m$\pm$0.005 m

Separation AC of adjacent maxima in interference pattern=21×10^{-3} m$\pm$ 1×10^{-3} m.

Wavelength λ of laser light, $=6.33\times10^{-7}$ m (negligible error)

Substituting these values for λ, AC, and D into equation (1) gives:

$$L=\frac{\lambda D}{AC}=1.54\times10^{-4}\ \text{m}.$$

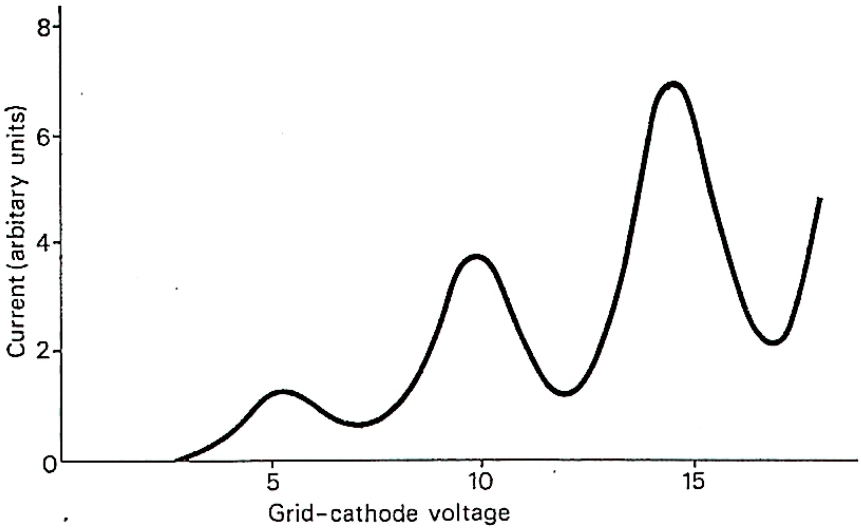


Figure 3

Knowing that the frequency of the ultrasound is 6.025±0.001 MHz, this being the frequency of vibration of the quartz oscillator, the velocity of the sound can be deduced immediately from the relation:

velocity=frequency×wavelength, i.e., velocity=926 ms^{-1}

Now try and answer the following questions on this experiment.

(*a*) Identify the dominant *source* of error in the final result for the velocity of ultra-sound waves in carbon tetrachloride.

(*b*) List *several* advantages of this particular method of measuring the velocity of ultra-sound waves in a liquid compared with a direct measurement of the time for a pulse to travel a known distance.

2 Franck-Hertz Experiment

Figure 3 is a reproduction of the actual current-voltage trace obtained in the broadcast as the voltage was increased to about 20 V. (There are in fact more dips at higher voltages, but at voltages greater than about 30 V the electron's energy is sufficient to completely remove an electron from mercury. Ionization (Unit 6) has occurred instead of *excitation* which happened at the lower voltage maxima. (The process of ionization was demonstrated in the television programme of Unit 6.) In the first current dip electrons have given up their energy to exciting mercury atoms in the vicinity of the grid. As the voltage is increased further, so increasing the electrons' kinetic energy, the current rises again—the mercury atoms evidently cannot absorb this new energy. However, when the voltage reaches a higher value the current drops yet again. What is happening now is that an electron is so rapidly accelerated on leaving the cathode that it reaches the excitation energy of mercury just about half way to the grid—where it is brought to rest. On reaching the grid it has again just the acceptable amount of energy which it 'feeds' to a mercury atom. In the case of the third dip the electron will have made two such collisions on the way to the grid. The voltage separation between successive minima (or maxima) is about 4.9 V and represents the first excitation voltage for mercury. (Because of 'contact potentials', the value of the voltage when the first dip occurs is not equal to the separation of subsequent minima.)

Why does the current value in a dip not fall exactly to zero?

Some electrons may reach the grid direct from cathode without hitting a mercury atom!

TELEVISION UNIT 31

Pre-broadcast Notes

The first part of the programme is a demonstration of radioactivity which you could not perform at home. The demonstration includes two applications of radioactivity in industry. The second part of the programme is an animated film of nuclear fission and how fission starts and is maintained in a conventional fission reactor. Lastly, there is an experiment which gives results from which it is possible to calculate approximately the diameter of an atomic nucleus.

Subjects
1 Radioactivity
2 The Size of an Atomic Nucleus

Speakers
Professor M. J. Pentz
Mr G. C. Fletcher
Dr A. J. Walton

Main Text

Before the programme you are advised to read Sections 31.3, 31.4.1 in relation to the radioactivity demonstration and the animated film on nuclear fission. It is also important to read *these* Broadcast Notes, particularly those that are concerned with the nuclear diameter experiment.

Synopsis and Notes

Radioactivity

Guy Fletcher, Visiting Fellow, Open University, demonstrates how it is possible to classify radioactivity into alpha-, beta-, and gamma-radiations. They can be crudely distinguished by noting their different abilities to penetrate various materials.

The next demonstration shows that a beam of beta-radiation can be deflected by a magnet, the conclusion being that beta-radiation is charged. This demonstration and the measurements can give you some idea about the radiation involved: whether it is positive or negative in charge and how massive it is.

The cloud chamber demonstrates a visibly more direct method of detecting radiation, as opposed to the complexities of the working of a Geiger tube. The two other demonstrations of *back-scattering* and *neutron activation* show applications of radioactivity. Guy Fletcher mentions some of the uses of back-scattering, but after answering the problem of the 1901 sixpence can you think of further applications for neutron activation?

Nuclear diameter experiment

In the second part of the programme, an experiment will be performed which yields a crude estimate of a nuclear diameter. In the experiment, different thicknesses of aluminium foil are placed in a beam of α-particles and the intensity of the beam emerging from the foils is measured. The method is based on 'shadowing'. When, as in Figure 1, the total area presented by the nuclei intercepting the beam approaches the area of the α-particle beam, the number of α-particles getting through will be drastically reduced. However, because the nuclei are randomly distributed it would take an infinite number of nuclei, and therefore an infinite number of foils to cut the beam off entirely. In fact a detailed analysis of the problem shows that when

Figure 1 is on p. 96.

$$\frac{I}{I_0}=e^{-1}$$

then

$$na=A$$

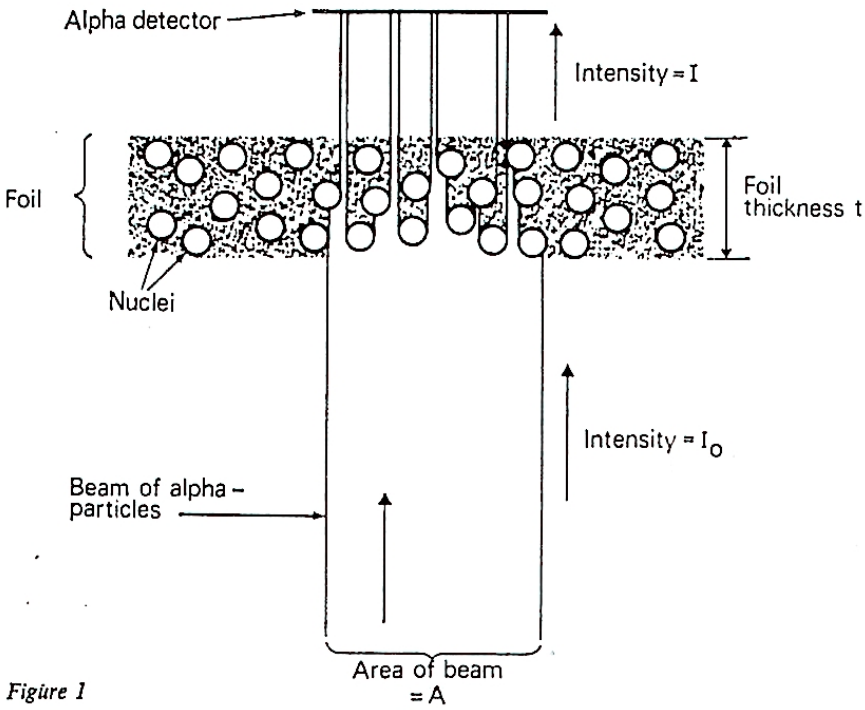


Figure 1

Here I_0=intensity of the beam incident on the foil

I =intensity of the beam emerging from the foil

e =exponential factor (≈ 2.718. See *MAFS*, Section 5C)

n =number of nuclei intercepting the beam

a =area presented by a single nucleus

A=cross-sectional area of the α-particle beam

Thus, when the foil thickness (i.e., the value of n) is such that the number of α-particles reaching the detector is about 1/3 (actually. 1/2.718) of the number reaching it with no foils present, then:

$$na = A$$

$$\therefore a = \frac{A}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

To evaluate a, we must know how n is related to the foil thickness t that gives the required reduction in the beam intensity. Since the number of nuclei is equal to the number of atoms, it follows that n is simply the number of atoms in a piece of the foil material of thickness t and area A, i.e., of volume At, i.e., of mass ρAt, where ρ is the density of the material. Now you will remember from the definition of *mole* (Unit 6) that for a material of relative atomic mass,* M, in M gm of the material there are Avagadro's Number, N_A, of atoms. i.e., in M kg of the material there are

1 000 N_A atoms or, in 1 kg of the material there are $\frac{1\,000 N_A}{M}$ atoms or, in

ρ At kg of the material there are $\rho At \frac{1\,000 N_A}{M}$ atoms.

*Relative atomic mass *used to be referred to as* atomic weight *and it is this latter name which is used in the programme.*

Substituting this number of atoms and therefore of nuclei into equation (1) gives

$$a = \frac{M}{1\,000\ \rho t N_A} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

enabling a to be determined.

Post-broadcast Notes

Detection of Radioactivity

In the programme, various pieces of equipment were used to detect the radiation from the sources used. Here are some explanatory notes on this equipment.

Methods of detection are indirect and rely upon the interaction of the radiation with other matter. Alpha- and beta-particles and gamma-radiation move quickly and possess energy. When they hit atoms of other matter, they hit the electrons surrounding the nucleus. In these collisions, an electron may be given sufficient energy to *remove it* from the atom; this is *ionization*. The presence of radiation can be detected by the ionization it causes; this is what the *diffusion cloud chamber* does. In the programme, you saw the tracks left by the alpha-particles given off by the decay of Thoron gas. The diffusion chamber is cooled to a very low temperature and contains a supersaturated alcohol vapour. As the alpha-particles pass through the vapour, ionization of the air occurs and alcohol vapour condenses along the trail of ionization left by the alpha-particle. This condensation trail is made more visible by shining a light on it. You may remember the jet-trail simile that Professor Pentz used in the TV programme of Unit 2. The other detector used was the Geiger-Muller tube (Fig. 2). This too depends upon the ionization that occurs when radiations pass into it.

The Geiger tube consists of an earthed, cylindrical tube with a thin mica window at one end and an insulated seal at the other. The tube contains an easily ionizable gas at a low pressure.

When radiation passes through the window, positive ions and negative ions (electrons) are formed in the gas inside. The negative ions move towards the positively charged anode. The movement of electrons causes further ionizations in the gas, and they all move into the anode in an 'avalanche'. These events happen in a few microseconds, and are registered as a large negative pulse at the anode. This pulse can be amplified to produce a deflection on a meter needle, or to produce an audible 'click' from a loudspeaker.

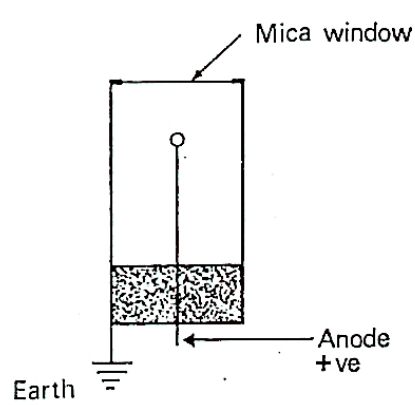


Figure 2

These pulses or clicks may be counted in two ways.

A *scaler* measures the number of pulses received in a measured time. Dr Walton used a scaler in the experiment to determine the size of the aluminium nucleus.

The alternative is to use a *ratemeter*, which measures the *rate of arrival* of pulses, and as used in the radioactivity demonstration is a useful indication of varying amounts of radioactivity.

Nuclear diameter experiment

In the programme, you saw how three foils of aluminium (each of thickness 3×10^{-2} m) reduced the count rate at the detector from 94 in 15 s to 49 in 15 s. In fact, to reduce the count to 94/3 ($\approx$30) in 15 s took five foils, i.e., $t=5\times(3\times10^{-6})$ m.

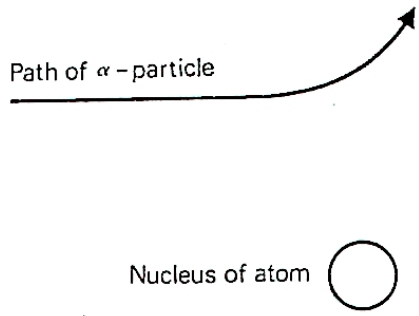


Figure 3

Substituting the following values: the atomic mass of aluminium

$$M = 27$$
$$= 2{\cdot}7\times10^{3}\ \text{kg m}^{-2}$$
$$t = 1{\cdot}5\times10^{-5}\ \text{m, and}$$
$$N_A = 6{\cdot}0\times10^{23}$$

into equation (2) gives

$$a \approx 10^{-24}\ \text{m}^2$$

Therefore, on taking the square root, the nuclear diameter is about 10^{-12}m.

Compare this estimate of the nuclear diameter with that of the atomic diameter as calculated from the density of aluminium.

Since there are N_A atoms in M gm of aluminium, there are 1 000 N_A atoms in M kg, i.e., there are 1 000 N_A atoms in $\frac{M}{\rho}\text{m}^3$.

$\therefore$ 1 atom occupies a volume of:

$$\frac{M}{1\,000\,\rho N_A}\ \text{m}^3$$

Substituting for M, ρ, and N_A gives an atomic volume of about 17×10^{-30} m or, on taking the cube root, a diameter of about $2{\cdot}5\times10^{-10}$ m.

So this crude experiment demonstrates that the nucleus is at least several hundred times smaller than the atom – in other words it vindicates the nuclear model of the atom. However, the value obtained with this particular set-up is some 200 times larger than the accepted nuclear diameter of aluminium! The reason for this discrepancy is not hard to find—our explanation (Fig. 1) assumed geometrical shadowing. In fact, both the α-particle and the nucleus are positively charged and can repel each other while quite far apart; a 'collision', namely, an event which deflects the α-particle so that it is not detected, can therefore occur when the α-particle is further out than a nuclear radius from the nucleus (Fig. 3).

An α-particle approaching closer to the nucleus than the one shown in Figure 3 will be deflected through a larger angle; an α-particle on a more remote path will be deflected through a smaller angle. So far as the detector is concerned the nucleus has a radius (and therefore a cross-sectional area) several times the geometrical radius. It was this larger cross-section which was suggested by the 'blobs' in the television experiment. The experiment also implicitly assumes that the attenuation of the α-particle beam is due only to the deflection of the individual particles out of the 'line of sight' of the detector. This assumption ceases to be valid at high attenuations. In fact to make an accurate measurement of the nuclear size one must use a very thin foil and study just how many α-particles are deflected at particular angles. Needless to say the analysis of the results is more difficult than the television programme!

TELEVISION UNIT 32

Pre-broadcast Notes

Subject
Elementary Particles
Speakers
Professor M. J. Pentz
Professor F. R. Stannard

This week you are to perform an experiment using bubble chamber photographs. What is involved in producing such photographs? In this programme we set out to answer this question. We take you on a systematic tour of the accelerator, the particle separation equipment, and the 2 metre hydrogen bubble chamber at CERN in Geneva (Fig. 6 of the Main Text). Before viewing the programme you should read Sections 2 and 3 of the Main Text. There you will find a description of the functions and operating principles of these instruments.

Post-broadcast Notes

During the making of the first part of the programme, the proton synchrotron was undergoing routine maintenance and so was not operating. This made it possible for Professor Pentz to enter the building that houses the linear accelerator, and also the synchrotron tunnel. These are normally inaccessible owing to the high level of scattered radiation from the accelerator.

Professor Pentz's tour began with the source of protons in the Faraday cage (Fig. 16 of the Main Text). He next showed the linear accelerator or linac (shown opened up in Fig. 12 in the Main Text). In the synchrotron tunnel he pointed out where the vacuum tube from the linac joined that of the synchrotron, and later where the protons left the ring. The target that the protons strike could not be seen because it was buried under concrete. The secondary beam from this target was followed into the East Experimental Hall. Professor Pentz described the layout of the beam with the aid of diagrams and then followed the line of the beam until it left the East Hall and entered another building where the 2-metre hydrogen bubble chamber was located.

At this point Dr Stannard took up the story and described the structure of the chamber by assembling a model. Photographs of the various parts of the actual chamber are shown in Figures 1 to 4 of these notes, and a

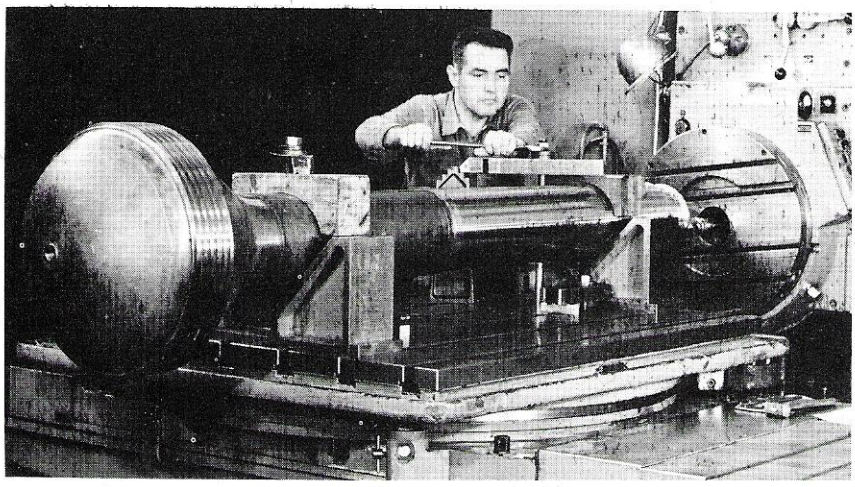


Figure 1 Adjustments being made to the piston of the CERN 2-metre hydrogen bubble chamber. When mounted vertically in the chamber it controls the pressure on the liquid. (Photo CERN.)

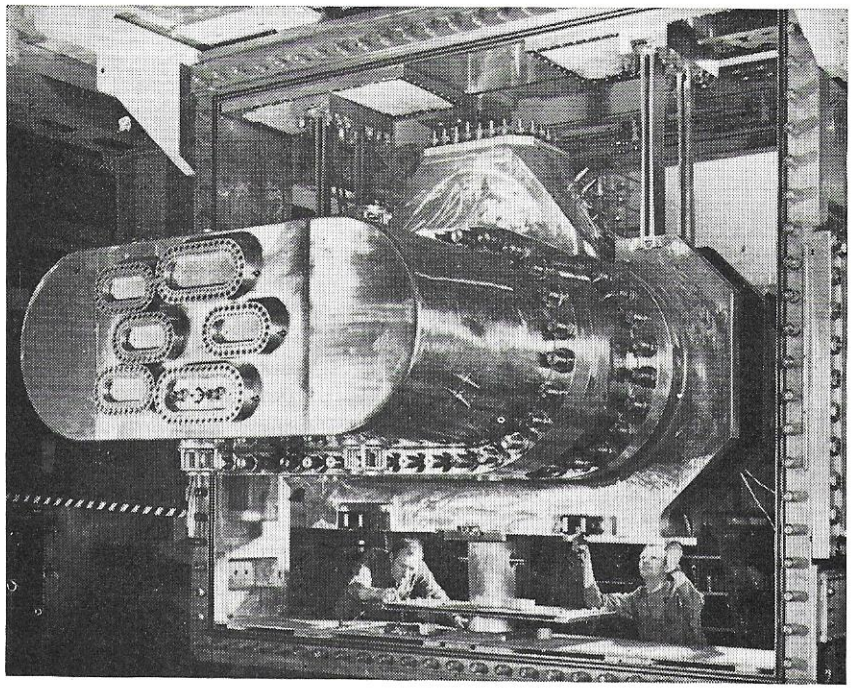


Figure 2 The 2-m chamber body with the safety tank on the camera side. (Photo CERN.)

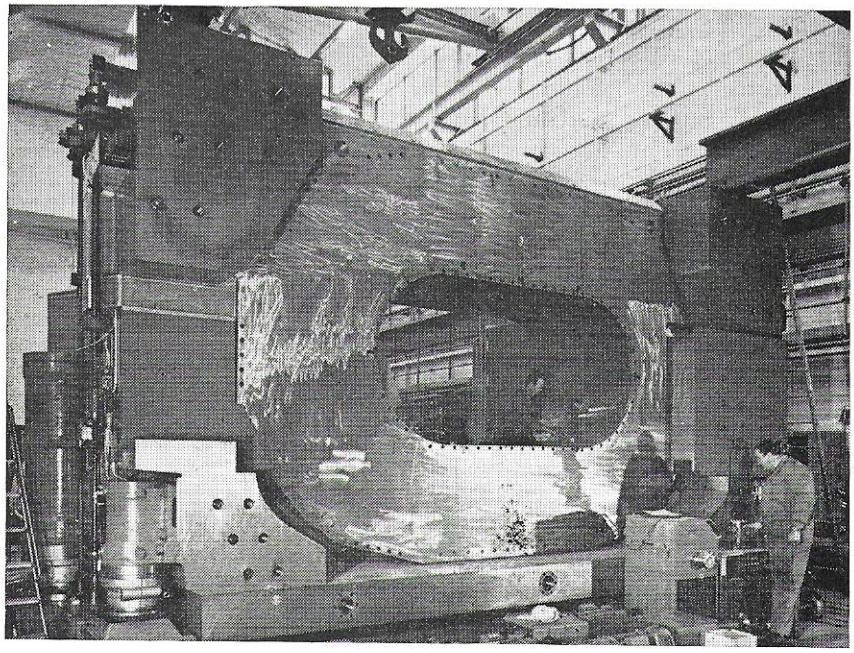


Figure 3 A coil and part of the iron belonging to the electromagnet of the 2-m bubble chamber. (Photo CERN.)

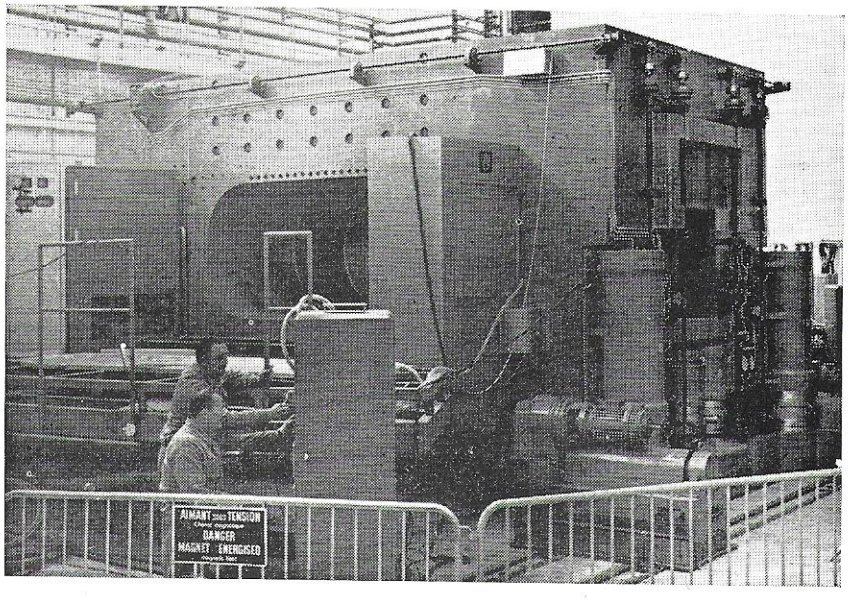


Figure 4 The electromagnet of the 2-m bubble chamber. (Photo CERN.)

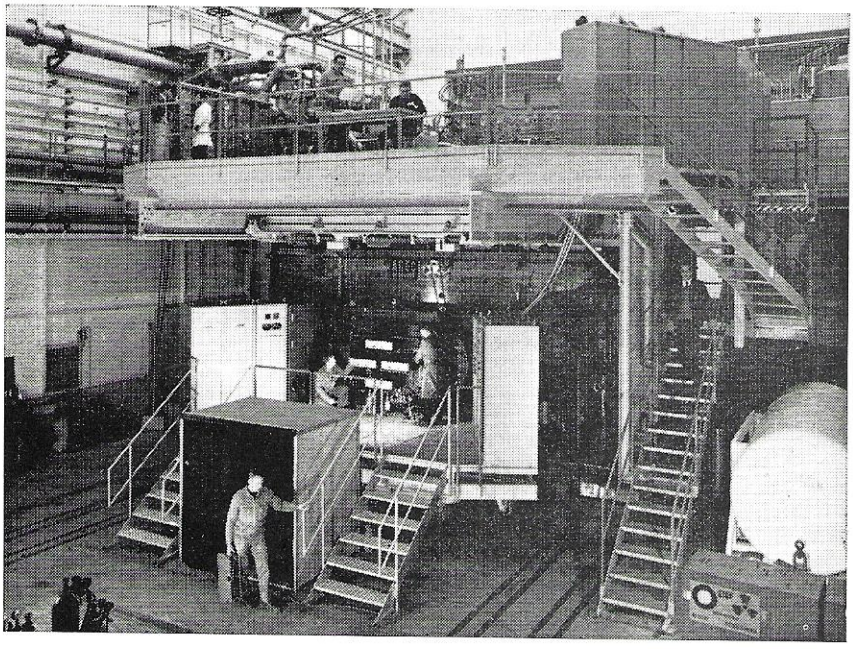


Figure 5 A general view of the 2-m bubble chamber. On the platform above the chamber is seen the equipment for compressing and expanding the liquid. (Photo CERN.)

general view can be seen in Figure 5. (Your overall impression of the chamber, however, may be more accurately portrayed by Fig. 6.)

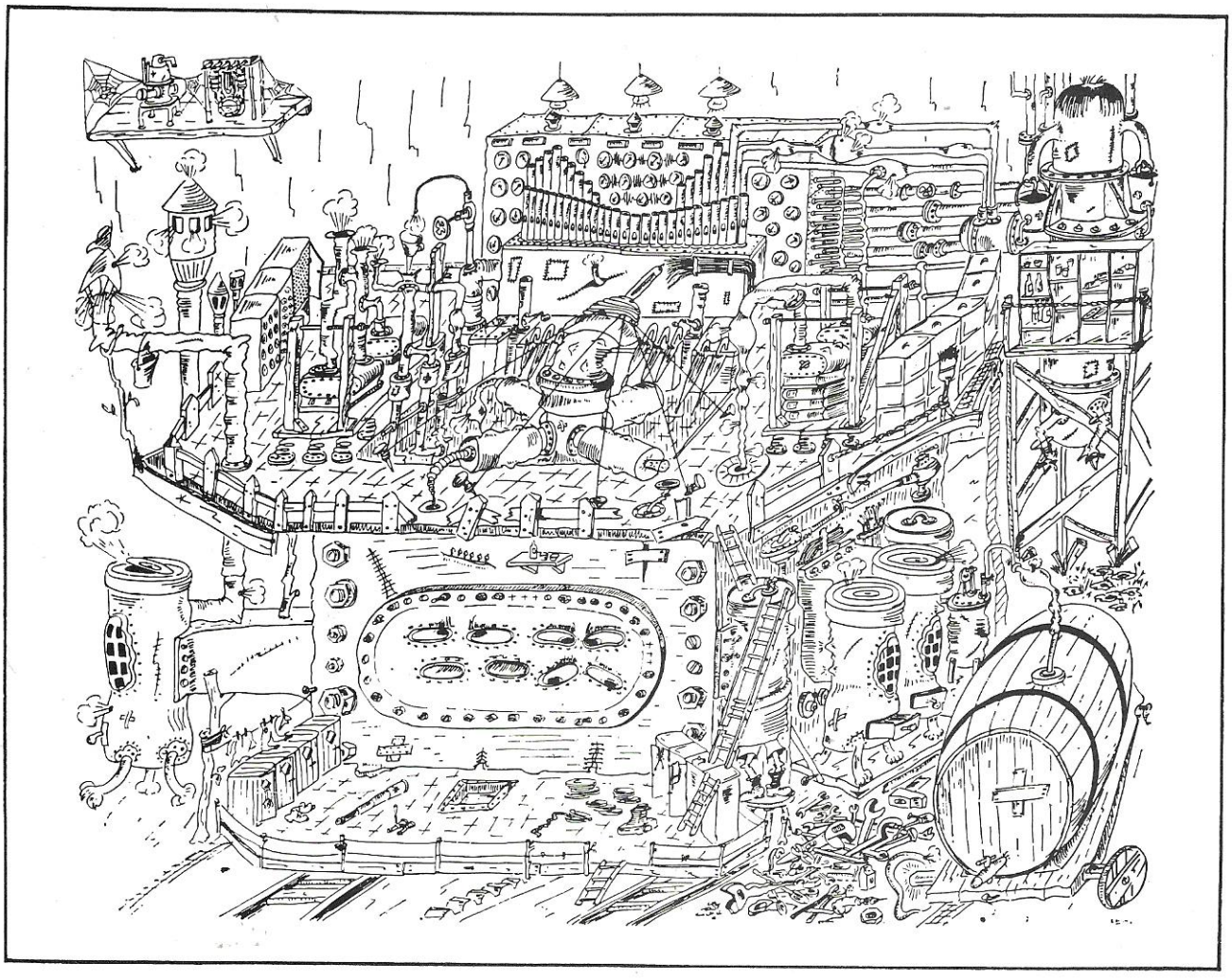


Figure 6 An artist's impression of the 2-m bubble chamber. (Courtesy CERN.)

The second part of the programme showed the accelerator being brought into operation. The maintenance men had first to be cleared from the synchrotron tunnel. The machine was then switched on from the main control room. While this was happening, Dr Stannard was in a second control room – the one associated with the running of the bubble chamber. There he pointed out a cathode ray oscilloscope screen displaying the variation of the chamber pressure with time. It also showed two blips, one representing the arrival of the beam and the other the flashing of the lights. The bubble chamber pictures you saw being taken and processed did not easily lend themselves to a project in which we could involve you. So the photographs supplied to you in connection with Home Experiment 2 had to be taken on a separate occasion with another bubble chamber. The procedure for obtaining these, however, did not differ appreciably from that shown in this programme.

TELEVISION UNIT 33

Pre-broadcast Notes

Subject
Science and Society I
Speakers
Professor M. J. Pentz
Dr J. B. Adams
Professor L. J. Haynes
Dr P. J. Smith
Professor S. Rose
Hilary Rose
Dr D. S. Davies

This programme is concerned with the British Government's decision of 1968 not to participate in the proposed 300 GeV project at CERN in Geneva. The aim of the television programme is not to present the student with factual evidence for and against the decision, but to show how people with different views present their case. We also hope to give some insight into how such committees as the Science Research Council reach their decisions.

It is important to distinguish between the various scientific activities going on at CERN, both the proposed new projects and those already in existence. In the television programme of Unit 32, you have already seen existing equipment. This consisted of the linear accelerator, the circular 28 GeV proton synchrotron and the liquid hydrogen bubble chamber.

Near the beginning of this programme (Unit 33), you will see Professor Pentz in Geneva pointing out the difference between the size of the comparatively 'small' 28 GeV ring already in existence, and that of the proposed 300 GeV ring.

When talking about the 300 GeV project, it is important to distinguish between the earlier proposal of 1964 and the later proposal of 1970.

The 1964 proposal involved the creation of an entirely new and separate European laboratory for high-energy physics, located at a site in Europe to be chosen from a number offered by the Member States of CERN, and built around the 300 GeV accelerator.

In 1968, the British Government decided not to participate in the 300 GeV programme. The other Member States of CERN nevertheless pursued their studies of possible sites and of the draft Convention for the new laboratory. But they encountered considerable difficulties, mostly political, in the choice of site. Meanwhile, the accelerator designers and physicists, under

the leadership of Dr J. B. Adams, Director of the 300 GeV project, produced an entirely new proposal.

This involved adding a 300 GeV accelerator to the existing CERN laboratories near Geneva, using the 28 GeV proton synchrotron as the 'injector' for the 300 GeV machine (just as the 50 MeV linear accelerator you saw in TV 32 is the injector for the 28 GeV machine), and using all the laboratory, workshop, computer and administrative facilities of the existing CERN—which, as you saw in TV 32, are very substantial. At the same time, the design of the accelerator itself was modified so as to incorporate the latest ideas, with the result that it was both cheaper and more flexible than the 1964 design. Thus, the final energy could be increased by stages in later years by the inclusion of additional magnets in the same ring or by the replacement of conventional magnets by more powerful 'superconducting' ones.

The new proposal was formally approved by the Council of CERN in mid-February 1971, and this time the British delegate was able to signify the support of the British Government for the project.

As Professor Pentz will point out, the television programme was made a very short while after this February 1971 agreement.

We are, however, concerned in this programme with the original 1964 project which was rejected by Britain in 1968, although you will hear references to the later project.

The programme can be broken down into three parts:

(i) In the first part Professor Pentz interviews Dr Adams.

(ii) We then return to the studio, where Professor Pentz joins a discussion between members of the Science Foundation Course Team, who have strong and differing views about the 300 GeV project. The Course Team decided to have this discussion in the television programme to give the student some idea of how scientists can have vastly different views about this whole area, even when they are from the same faculty at the same university.

(iii) The programme concludes with an interview of Dr Duncan Davies by Hilary Rose on the subject of what sort of criteria are used by, for example, the SRC in order to make a decision about such projects as the 300 GeV accelerator.

Hilary Rose is a lecturer at the London School of Economics, with a special interest in this area of scientific decision making, and is also a consultant to the Science Foundation Course Team for this Unit.

Dr Duncan Davies is General Manager of Research and Development at Imperial Chemical Industries, and a member of the Science Research Council. He did not, however, take part in the SRC discussions on the 300 GeV project with which we are concerned in this Unit, and his points are of a more general nature about this whole area of scientific decision making.

We have deliberately not given any post-broadcast notes for this programme, as it has not been made as a means of presenting factual evidence; this you will find in the main text of the Unit. The programme is designed to show how the protagonists present their cases and answer each other's points.

Subject
Science and Society II

Speaker
Professor M. J. Pentz

Pre-broadcast Notes

Like the television programme of Unit 33, this programme is not didactic or expository. We would like you simply to sit back, look, listen and think. We hope you will get some idea of the general debate in an area which is becoming increasingly important as more and more money and resources go into science and technology. We focus attention in this programme on the questions: 'Is science really "neutral"?'; 'Can the scientist really afford to ignore the possible consequences of his research, however "fundamental" it may be?'; 'Can society afford to "leave it to the politicians" to decide what science gets supported and what is done with the results?'

You have been studying in this Course Unit two examples of the large-scale application of science, nitrogen fixation and nuclear energy. They both illustrate the fact that science can be misused unintentionally, that a scientific application can have socially undesirable side affects which, whether they were foreseen or not, were not part of the original goal. Obviously the incidental or accidental radioactive contamination of our environment is not the desired end-product of nuclear power! But it is important to realize that in many cases science is applied deliberately, with premeditation, to ends which most people would consider socially undesirable. The defoliants and anti-personnel bombs used in Vietnam were designed for that purpose. In fact, a very large proportion of the effort – money and manpower – going into science has such goals. Not surprisingly, this is causing concern among scientists, and particularly among American scientists who have been so directly confronted with the problem in the context of the Vietnam war. So we went to the USA – to Harvard, MIT and Yale – to talk to some of the people involved in the argument. As you will see, there *is* disagreement and confusion among the scientists themselves about where their responsibilities begin and end.

In a short programme like this you can only get a glimpse, a fleeting impression, of the attitudes and arguments and of the *people* who express them. We hope that this will nevertheless provoke thought and discussion–which we will take up again in the Radio component of this Unit.

Post-broadcast Notes

This programme should at least have raised a number of questions in your mind.

Who decides how science is applied?

In whose interests *is* it being applied?

Is it really true that *applied* science is controlled by economic and political forces, but *basic* science must remain apolitical?

Has science no purpose except to increase knowledge?

Do you agree that the *technologist* has a choice, but the scientist has not? Should scientific research be a matter for public decision making or should decisions about funding of science be left to the politicians?

Are the problems of the use or misuse of science *societal* as well as scientific?

If so, what does this imply for the scientist – or for the student of science?

Should science and scientists be divorced from politics, or are they involved in politics anyway, because their work is going to be used sooner or later?

Can science really be 'neutral'?

We do not expect you will have all the answers now – or after the radio programme where we shall be discussing these questions further. But we *do* expect that you will have been provoked by this programme, by this final Unit of our Course and, indeed by the whole Course, to think seriously about the social consequences of science, to go out and seek further knowledge, and above all to *act* upon that knowledge. The survival of science – and of society – may depend upon what you do.

TELEVISION UNIT A

Pre-broadcast Notes

Subject
Time

Speakers
Professor M. J. Pentz
Professor F. R. Stannard

This television programme is not directly linked with any particular Unit in the Course, although it does take a backward look at an important law of nature that you met in Unit 5 – the second law of thermodynamics. Note that we say 'a backward look', implying that Unit 5 came *before* this TV interlude. Have you stopped to consider the question of how you know the direction of time? How can you tell whether event A happened before or after event B? How do you distinguish between 'past' and 'future'?

In this television programme Professor Pentz and Professor Stannard deal with this question with the aid of various peculiar film sequences and other tricks. We would like you to sit back and enjoy this programme. If it also stimulates thought about 'the arrow of time' and leads you to wonder about some things we all just tend to take for granted, so much the better.

Post-broadcast Notes

So we have established three 'arrows of time', the increase of entropy, the divergence of electromagnetic waves, and the expansion of the universe.

Are these three related? What, indeed, *are* the fundamental relationships between space, time and matter?

We do not take these questions further in this Course. If your interest in them has been aroused you should think of further studies in the fundamental ideas of physics. We are, in fact, planning a Course on 'space, Time and Matter', which will pick up the story where we leave it with this programme. Perhaps you should think of enrolling for that Course when it is available.

TELEVISION UNIT B

Pre-broadcast Notes

Subject
The sulphur-dioxide and Drosophila experiments

Speakers:
Professor M. J. Pentz
Professor Steven Rose
Dr M. E. Varley

This programme – the last of the Course – is devoted to showing you some of the results of your own work, the Drosophila experiment you did in the summer, and, more recently, your measurements of sulphur dioxide in the atmosphere.

Steven Rose will present your sulphur dioxide results and discuss their significance. Peggy Varley will tell you about this year's results in collecting and breeding *Drosophila subobscura* and *Drosophila melanogaster* and their parasites.

The broadcast is transmitted after the examination day because we think you will have less on your mind then and can more easily afford to take time off to see how these two unique experiments went this year.

Post-broadcast Notes

With this television programme and the associated radio programme we come to the end of our Foundation Course. It is appropriate that the last programme, like the first, is concerned with experiments you have been doing in your own home. We think you will agree, reviewing the range of these experiments, from the Galileo inclined plane experiment with which you began, to the *Drosophila* experiment, or the atmospheric pollution measurements, that none were trivial. This underlines one of the points we made at the very beginning of the Course – that you don't need expensive, bulky or dangerous equipment to learn the experimental basis of science.

We hope too, that through participating in these quite unique experiments, which could not be done by students in any other University but ours, you have got a sense of involvement, both with your fellow students and with us in the Course Team, which may offset slightly the feeling of isolation you may have had at times.

INTRODUCTORY PROGRAMME

Pre-broadcast Notes

Subject
The Science Foundation Course

Speaker
Professor Michael Pentz

The Dean of the Faculty of Science, Professor Michael Pentz, will talk about the aims of the Course and the methods by which it will be taught.

This broadcast will supplement the *Introduction and Guide to the Science Foundation Course*, which you received in the first mailing, and it will be closely related to the Introductory TV programme.

It would be a good idea to read the *Introduction and Guide* again before you listen to the broadcast. There may be some 'stop press' items in the broadcast, so have a pencil and paper handy.

Post-broadcast Notes

As for the Introductory TV programme, the *Introduction and Guide to the Science Foundation Course* should serve as 'post-broadcast notes' for this programme.

If there are any queries about the Course that you may have after listening to this radio broadcast, you should let your Counsellor or your Tutor know what they are. Counsellors and Tutors will be glad to pass on to us at Walton Hall any questions that they cannot answer themselves. We will then try to answer them in the few minutes we are keeping free for such purposes at the end of each radio broadcast.

RADIO UNIT 1

Pre-broadcast Notes

Subject
Puzzles, Problems and Enigmas

Speakers
Professor S. P. R. Rose
Professor John Ziman

Unit 1 describes the activity of science and how it developed as a human activity in society. The Unit gives you an idea of what it feels like to be a scientist and the Radio programme will explore this idea a little further.

Dr Steven Rose, Professor of Biology at the Open University, will introduce a distinguished physicist, Professor John Ziman F.R.S. of the University of Bristol, whose book about science, *Public Knowledge*, is one of the recommended background reading books for Unit 1.

John Ziman will explain the fascination of science for him. He considers puzzle-solving to be one of the major activities of science. It is like doing crossword puzzles, but much more exciting. However, the deepest part of science is not just concerned with little puzzles, but with major problems of the interpretation of the nature of the universe around us. It is the tackling of these problems that converts science from a minor to a major activity in human affairs.

Steven Rose will relate John Ziman's remarks on science to the ideas expressed by Professor T. S. Kuhn in his book, *The Structure of Scientific Revolutions*, another recommended background reading book for Unit 1.

Post-broadcast Notes

Professor Rose introduced the programme by saying that the Science Foundation Course aimed at giving students more than what might be called 'the facts' of science. Science certainly contained facts but it was much more; it was a major force in human affairs. Unit 1 had tried to give some idea of what 'being a scientist' meant. Performing the Galileo experiment should have helped in understanding this.

Professor Ziman spoke of the fascination of science. Scientific research was like solving puzzles and gave the same pleasure as solving a crossword puzzle. Yet scientific puzzles were very difficult and their solutions often took months, years and even centuries. Certain puzzles had to be left for later generations to solve.

Much of the pleasure in science lay in the fact that one was not alone. Colleagues throughout the world were working on the same part of the puzzle. The only strict rule in science arose from the fact that it was a shared activity: one's answer to any scientific question had to satisfy other scientists. They had to be able to repeat what one had done. The purpose of science was to create a body of *public* knowledge.

That research was very far from a mechanical process was shown by the great number of errors to be found in the archives of science. Therefore puzzle-solving within the boundaries of an established scientific discipline was by no means uncreative. As puzzle after puzzle was solved, within some orthodox framework of theory and method, new *problems* would arise which could be easily formulated but which had no obvious answers. For the best pure scientists, the attempt to solve problems was the real goal of research.

Problem solving was very difficult because it demanded a great amount of insight and imagination. Yet it was wrong to assume that only speculative imagination contributed to the overall progress of science. A great deal of academic research that appeared on the surface to be no more than puzzle solving was in fact aimed at some larger problem and could help by clearing away minor errors and uncertainties. Both types of research worker were needed – those with imagination and those with scholarship – to maintain a balance between new conjectures and well-established facts.

All branches of scholarship maintained a certain conservative spirit to preserve the hard-won truths of the past. In this respect, the scientific community often put obstacles in the way of revolutionary thinkers. Although the active scientist had to be a revolutionary at heart, ready to overthrow old ideas once he doubted them, mature experience should not be discarded recklessly.

The highest scientific recognition was given to revolutionary geniuses who did more than solve problems. Men like Galileo, Darwin or Wegener saw that problems, enigmas, existed and proposed them for scientific investigation. This involved unhibited curiosity, without which the existence of an enigma could not be perceived.

Professor Rose related Ziman's remarks on science to the ideas expressed by Thomas S. Kuhn in his book *The Structure of Scientific Revolutions.*

Kuhn had argued that most scientific work – what he called 'normal science' – was of the puzzle-solving kind. But there was also a 'revolutionary science' in which major new theoretical insight suddenly transformed a scientist's ideas about a problem.

RADIO UNIT 2

Pre-broadcast Notes

Professor Baez will speak about how man has extended the range of his senses and thereby his knowledge of the universe by using sounds he cannot hear and light he cannot see. His senses include sight, hearing, touch and smell, but this talk will be concerned almost exclusively with sight and sound.

Subject
New light – new knowledge extending the range of man's senses
Speaker
Professor A. V. Baez (visiting professor of physics at the Open University)

You can appreciate the relative importance of the senses by doing a thought experiment. Suppose you were blindfolded and were brought, under cover of darkness, to the middle of a huge dark cave. Left alone, how would you determine the nature of your surroundings? Your senses are in perfect order but there is no light and no sound and apparently nothing to feel, as you

discover by groping, in vain, with your arms outstretched. You throw pebbles in all directions and hear them land in the distance. When you yell the echoes suggest that there are distant walls. But how meagre is your knowledge of your surroundings without sight! Note that you were able to produce sounds, but you have no means on your body to produce light. Now assume that you are permitted to light a candle. Holding it high you fill the entire chamber at once – or so it seems – because light travels so fast that without special instruments you cannot detect light echoes.

You can now, in the dim light, see stalactites on the ceiling and barely perceive the distant walls. You know at once that you are in a cave. You now sense how appropriate is the meaning of the word 'enlightenment'. It is clear from this example that the range of our experiences increases dramatically as we pass from touch, to sound, to light.

As you will undoubtedly have guessed from the title, Professor Baez's talk will be closely related to the Main Text of Unit 2, and he will be referring to some of the figures in the text. So we advise you to read the text – especially Sections 2.1 to 2.3 – before you hear the broadcast, and to have it handy at the time.

Post-broadcast Notes

The logical follow-up to this broadcast is, of course, the rest of the Main Text of Unit 2 – from Section 4 onwards, where we pick up the theme where Professor Baez left off, and discuss the need for quantitative measurement, and for extending the scale of measurement.

And, in a broader sense, the whole of the Course that follows will provide detailed examples – some of which Professor Baez mentioned in the broadcast – of the theme of this Unit, for observation and measurement are the very foundations of all science.

RADIO UNIT 3

Pre-broadcast Notes

Subject
Studying Unit 3
Speakers
Professor M. J. Pentz
Dr A. J. Walton

In the Introductory Radio and Television Programmes we discussed study methods in general terms. In this radio programme, we apply these general ideas to the particular problem of studying one Course Unit i.e. Unit 3.

Experience in 1971 showed us that many students were making unnecessarily heavy weather of their studies – spending far too long over trying to learn the wrong things in the wrong way. By the time we realized what was going on, we had already reached Unit 10. So we devoted a special radio programme to a discussion on 'how to study a Unit efficiently and in a reasonable time', using Unit 10 as an example.

This year we will do a similar thing, only with an earlier Unit as our example. We have chosen Unit 3 because we expect that for many students – especially those without any previous experience of studying science – this Unit may prove to be the first real stumbling block. Because the intrinsic difficulties of the Unit may be greater than those of Units 1 or 2, it is all the more important to tackle it in the most effective and economical way. The radio programme is intended to help you do this.

Post-broadcast Notes

The best follow-up to this broadcast would be to make a systematic effort to apply some of the study techniques suggested. You will find a reminder of some of the points made in this broadcast in Section 4 of the *Introduction and Guide*, which we advise you to read over again now.

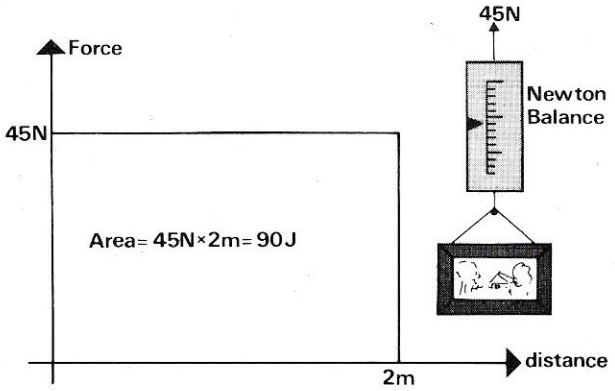


Figure 1 Shows the force required to lift an object (a particular picture) through a vertical distance of 2 m.

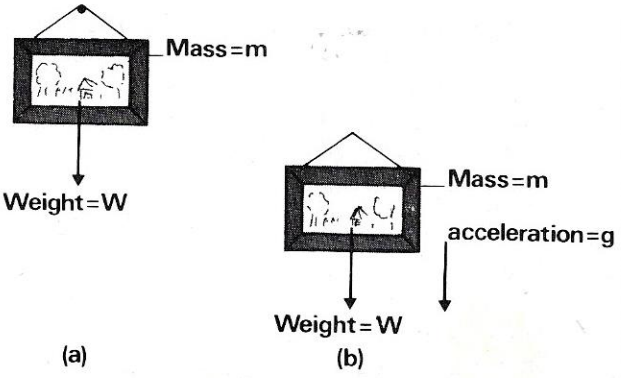


Figure 2 (a) When the object of mass m *is released as in (b) it accelerates downwards (b) with an acceleration* g.
From Newton's Second Law (force = mass × acceleration), W = mg
Assuming that W *is independent of whether the object is static or accelerating, the gravitational force acting on the body will be a constant at* mg.

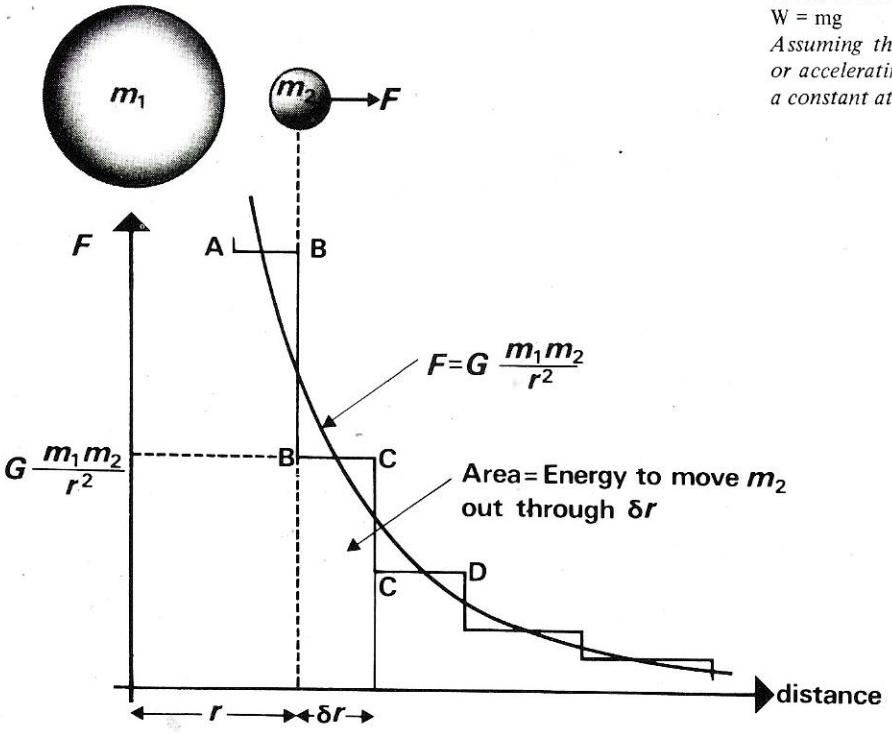


Figure 3 Illustrating how the force F *required to move a rocket of mass* m_2 *out from the Earth's surface depends on the distance moved. The actual force variation is shown in heavy line; the approximate variation by a series of steps.*

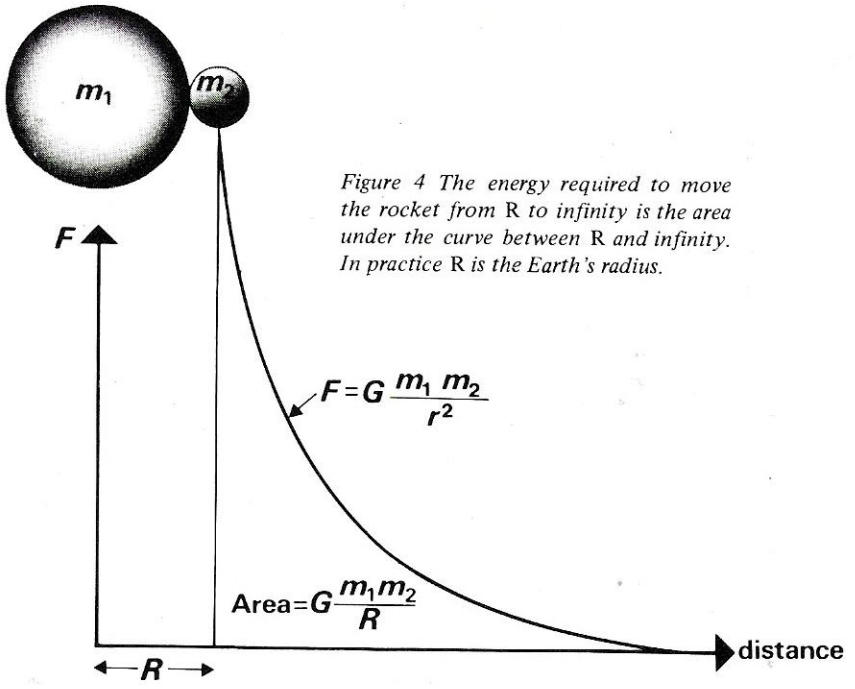


Figure 4 The energy required to move the rocket from R *to infinity is the area under the curve between* R *and infinity. In practice* R *is the Earth's radius.*

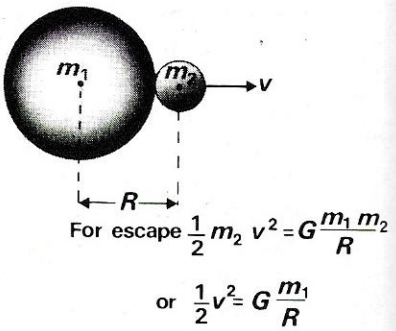


Figure 5 To escape completely from the Earth the rocket, of mass m_2, *must be given a velocity* v *such that its kinetic energy* $\frac{1}{2}m_2v^2$ *equals* Gm_1m_2/R, *the energy required to remove* m_2 *to an infinite distance from* R.

RADIO UNIT 4

Pre-broadcast Notes

Subject
Force and energy
Speaker
Dr A. J. Walton

This programme aims at filling out the somewhat brief discussion of potential energy given in Section 4.4.3. Although the examples given in the broadcast are all to do with gravitational potential energy there are obvious parallels with electrostatic potential energy since gravitational and electrostatic forces vary with the inverse square of distance between the masses or charges; we hope these parallels will suggest themselves as you re-read Section 4.4.3 after the broadcast. Before listening it is essential that you read Sections 4.4.1 and 4.4.2 – this much will be assumed in the broadcast. It is also essential that you have these notes in front of you since Dr Walton will refer to the diagrams during the broadcast. You should *not* attempt to read the captions while listening. These serve as 'post-broadcast notes' and should remind you of key points in the arguments.

Post-broadcast Notes

Figures 1 to 5 are referred to during the course of the broadcast. We hope the captions will serve as reminders of the key points in the argument. You should aim at reading Section 4.3 again, after the broadcast, especially if you found it tough going the first time round.

RADIO UNIT 5

Pre-broadcast Notes

Subject
Water, The Eccentric Fluid
Speakers
Dr. Felix Franks, Manager, Biophysics Division, Unilever Limited.
Dr Malcolm Tait, Manager, Biophysical Chemistry Division, Unilever Limited.

Figures 1 and 2 are on p. 6.

We take water for granted, but for the scientist it is one of the most exciting liquids on Earth. It has the most unusual physical properties and if it were not for these, the whole history of life on Earth would have been different, if indeed there would have been any life at all!

Have you ever thought of the role water plays in life? Have you wondered why substances that are very similar chemically boil at such different temperatures? Think over these questions and read Sections 5.4 to 5.7 of the Main Text before the broadcast. You should have the Figures 1 and 2, at hand for easy reference during the programme, because Dr Tait will refer to them specifically from time to time (see also Fig. 14 in Main Text).

Post-broadcast Notes

The main points that were made in the discussion could be summarized in the following terms:

We tend to forget that water is of critical importance for all life processes. Relatively tasteless and apparently characterless on first inspection, it has unusual properties which have influenced all forms of life. It has an unexpectedly high boiling point; ice, the solid form of water, is less dense than water itself; water has a high specific heat; and these are only a few of the common physical properties which are unique to water.

But to understand why water has unique properties we have to look at the behaviour of individual water molecules. This is done by examining the structure of water through the use of various refined techniques such as X-ray diffraction and infra-red radiation. Several conceptual models have

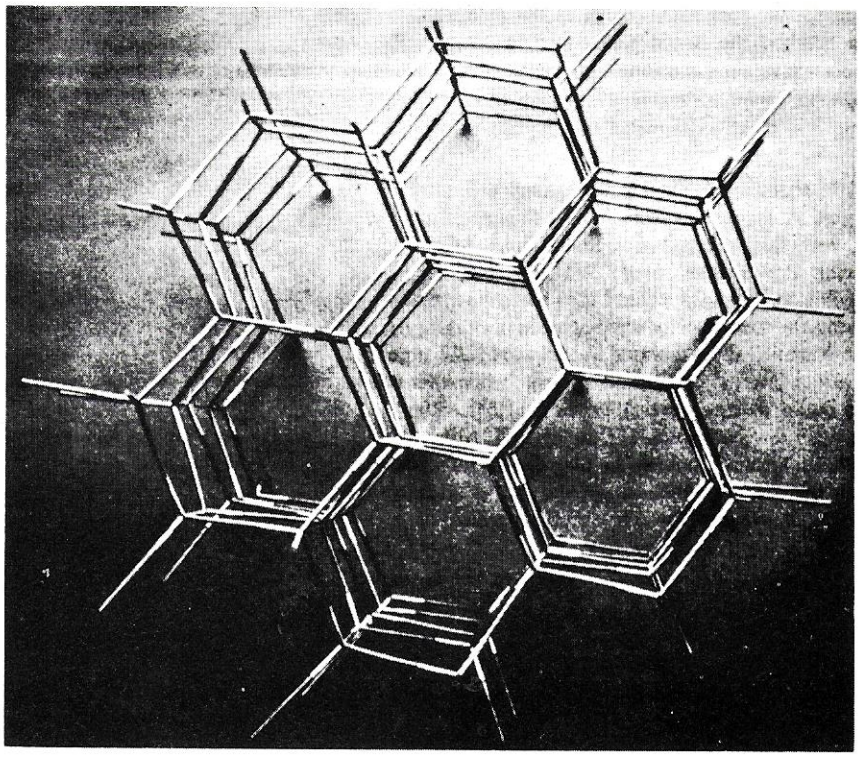


Figure 1 Molecular model for structure of water based on structure of ice.

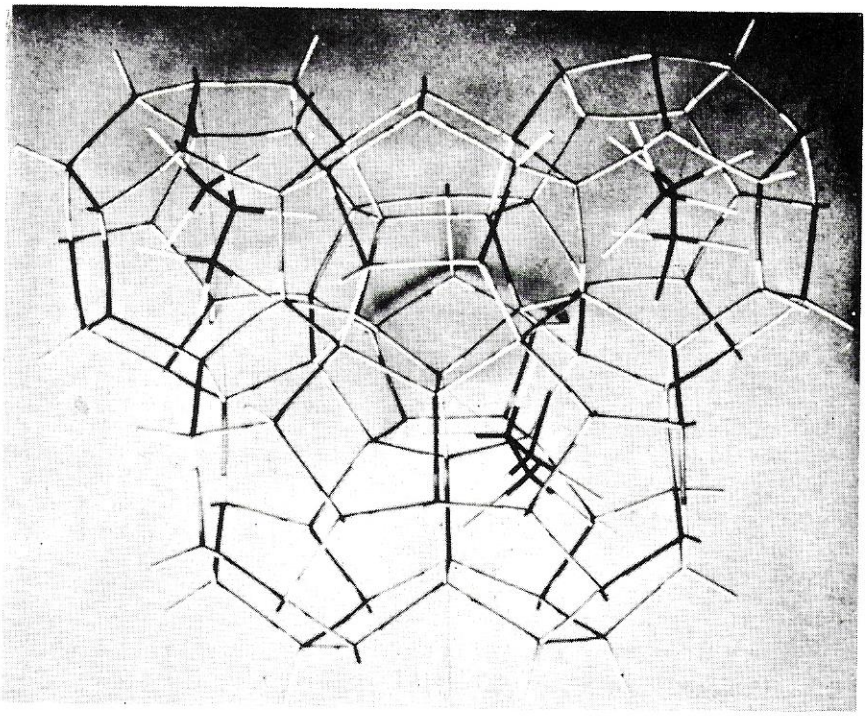


Figure 2 Molecular structure of propane gas hydrate.

been proposed for the structure of water and two are outlined, one based on the structure of ice and another based on the structure of propane gas hydrate.

Having examined water on the molecular level, we turn to questioning why water in bulk is so different from a collection of single water molecules. So we look at the sensitivity of water to charged ions and see how the structure of water changes as the distance increases away from the ion. Finally, using a protein molecule as an example,we demonstrate that if the structure of water is changed, even in a subtle way, it can have disastrous consequences on biological and chemical processes.

RADIO UNIT 6

Pre-broadcast Notes

1 Aim of the programme

This programme deals with the life and times of John Dalton – an English scientist. Dalton is of particular interest because it was he who first realized the existence and importance of atomic weights.

Subject
John Dalton
Speakers
Professor L. J. Haynes
Dr F. Greenaway
Anthony Hall

In the first part of the programme Professor Haynes describes the climate of social and scientific thinking which existed in the fifty years prior to Dalton's discoveries.

In the second part Dr Greenaway tells more about the man himself, and then, with quotations from Dalton's own writings, explains how it was that Dalton came to formulate the idea that each element consisted of particles of the same weight and that the particles of each element were different from those of all other elements – that is the theory of Atomic Weights.

2 Instructions to student

On pp. 8-9 of these notes you will find an historical chart which shows the work of Dalton's forbears and contemporaries. You may find it useful to glance through this for extra background before seeing the programme. You will see that the period 1750-1850 was an exciting, perhaps turbulent one, in all fields of life.

Post-broadcast Notes

1 Summary of programme

The historical chart shows the background to this period of great scientific and social activity. You are not expected to know all these facts – they are there for your information only. You should however remember just what it was that Dalton did.

John Dalton was at first a meteorologist. His interest in meteorology led him to work on the behaviour of mixtures of gases and on the solubility of gases in liquids. In his explanation of this behaviour he assumed that air and water were composed of very small particles. The discovery that air was composed of two gases, oxygen and nitrogen, raised the question: 'Why did the two gases not separate into two layers as would oil and water?' This question forced Dalton to consider the properties of the individual particles and eventually to form the conclusions that:

(i) all the atoms of a given element had the same mass;

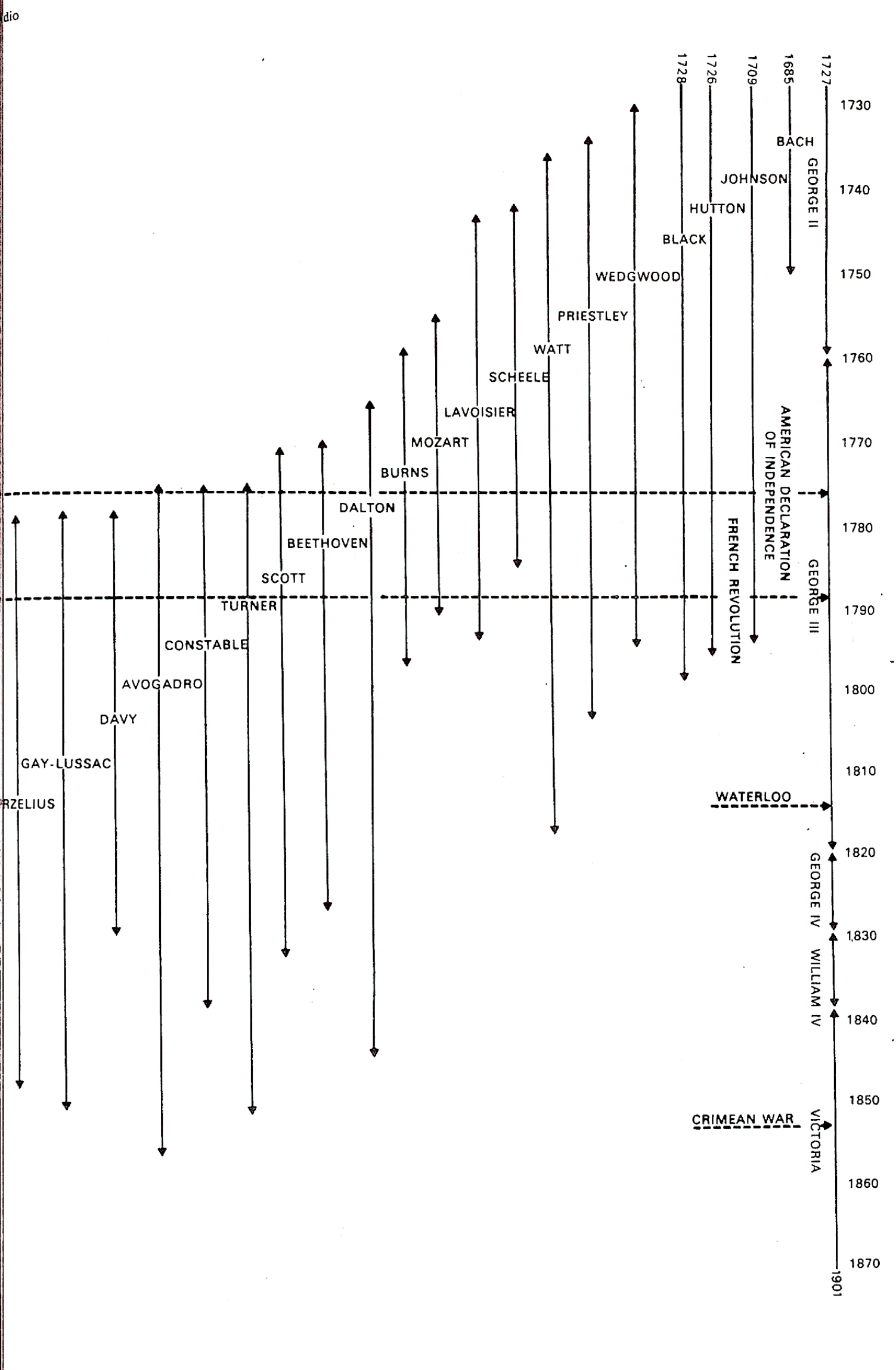
(ii) it was possible to calculate the *relative* masses of these atoms, in spite of their small size, simply because in a compound the same ratio of composition by mass must apply at *any* scale, from a large specimen on the laboratory bench right down to the constituent molecules. For example, if carbon monoxide consists of 42.8 per cent carbon and 57.2 per cent oxygen, and if the formula of carbon monoxide is CO, then it follows that one atom of oxygen has a mass $\frac{57.2}{42.8}$ the mass of one carbon atom.

This deduction, which in retrospect looks so simple, was the key to the whole concept of relative atomic mass (atomic weight) developed by Dalton.

You can see that making this deduction involves knowing that the carbon monoxide molecule is made up of one atom of carbon and one atom of oxygen. Dalton did *not* know this: to make progress he had to make some *assumptions*. He assumed that if two atoms A and B combined to form only one compound, then that compound would be of the type AB.

Continued on p. 10 of these notes.

	Literature, Music, Painting	Technology	Chemistry and Allied Sciences	Social and Political
1730		*Newcomen,* steam engine		
1740	*Handel.* 'The Messiah'	*Harrison,* marine chronometer		
1750	*Fielding,* 'Tom Jones' *Johnson,* 'Dictionary'			
1760		*Roebuck,* Carron Iron Works *Hargreaves, Crompton, Arkwright,* spinning machinery		*Voltaire,* The Enlightenment *Rousseau,* 'The Social Contract'
	Goldsmith, 'Vicar of Wakefield'		Founding of the Lunar Society	
1770			Isolation of oxygen Isolation of nitrogen	*Cook,* Voyage to Australia *Adam Smith,* 'The Wealth of Nations'
	Sheridan, 'School for Scandal'			
1780		The Coalbrookdale Bridge *Boulton and Watt,* steam engine The Power Loom	Combustion recognized as reaction with oxygen *Jenner,* Vaccination *Lavoisier,* elements of chemistry	*Paine,* 'The Rights of Man'
1790			Mob destroys Priestley's house	
1800	The Lake Poets	*Trevithick,* high pressure engine	Formulation of the law of constant composition	*Malthus* on Population
1810	*Jane Austen,* 'Pride and Prejudice'	*Bramah, Maudslay, Whitworth,* machine tools	Isolation of sodium and potassium Isolation of magnesium *Dalton,* Atomic Theory *Davy,* Isolation of chlorine	
1820	*Beethoven,* Ninth Symphony			*Bentham and Mill,* Utilitarianism
1830		*Stephenson,* locomotive The Telegraph	Isolation of aluminium *Wohler,* Synthesis of urea	University of Durham, the first to be founded in England since Oxford and Cambridge. University of London
1840				
1850	The Pre-Raphælite Movement			
1860				*Marx and Engels,* 'The Communist Manifesto'
1870				


1728
1726
1709
1685
1727
1730
BACH
GEORGE II
JOHNSON
1740
HUTTON
BLACK
1750
WEDGWOOD
PRIESTLEY
WATT
1760
SCHEELE
LAVOISIER
MOZART
1770
AMERICAN DECLARATION OF INDEPENDENCE
BURNS
DALTON
1780
FRENCH REVOLUTION
BEETHOVEN
SCOTT
GEORGE III
1790
TURNER
CONSTABLE
1800
AVOGADRO
DAVY
GAY-LUSSAC
1810
RZELIUS
WATERLOO
1820
GEORGE IV
1830
WILLIAM IV
1840
1850
CRIMEAN WAR
VICTORIA
1860
1870
1901

Such assumptions were all-important to Dalton's subsequent detailed examination of the numerical relations between the percentage compositions of compounds and the relative masses of atoms. Some of Dalton's assumptions were later shown to be incorrect but the central concept – that relative atomic mass can be determined from percentage composition – represented a tremendous step forward and formed the basis for the spectacular advances in chemistry which followed.

RADIO UNIT 7

This will be a feedback programme. The notes associated with this programme will be sent to you in a separate mailing.

RADIO UNIT 8

Pre-broadcast Notes

Subject
Mendeleev and the Periodic Table
Speaker
Mr F. Greenaway

This programme is about the development of the modern idea of a chemical element, and about the attempts at classification of the elements by their properties, which led to the construction of the Periodic Table. The story begins with Robert Boyle in the seventeenth century and reaches its climax with the Periodic Table of D. I. Mendeleev in the second half of the nineteenth century.

It is told by Mr F. Greenaway, Keeper of Chemistry, the Science Museum, London.

Mendeleev's Periodic Table of 1871 is shown as Table 1 in the main text of Unit 8 (page 10). Table 2 is a version updated to the 1930s (page 11). The Bohr Periodic Table, based on atomic number and electronic configuration rather than relative atomic mass and chemical properties, is shown in Table 4 (page 15).

Post-broadcast Notes

1 Summary of the programme

The idea of elements was needed to make the world of matter understandable. But the earth, air, fire and water of the ancient Greeks, being only ideals, were of little practical help. The modern idea of elements as '. . . simple substances which are the ingredients of which all composite substances are formed and into which they are ultimately resolved' began with Hon. Robert Boyle in the seventeenth century. In 1789, Lavoisier listed thirty elements, which he classified by their chemical properties. Some, he correctly suspected, were not true elements. Dalton's atomic weights provided the possibility of classifying elements on a numerical basis.

In 1817, J. W. Dobereiner noticed 'triads' of elements with similar properties, the atomic weight of one of them being halfway between those of the other two, e.g. Cl (35.47), Br (78.38), I (126.47).

By 1860, about sixty elements had been discovered and their atomic weights accurately measured. It became apparent that it was the ordering of elements by atomic weight that was the key to a useful classification. Several people worked on these lines. William Odling produced tables of elements in 1857 and 1865. J. A. R. Newlands' tables emphasized his *law of octaves*. Lothar Meyer and Mendeleev both produced periodic tables which, despite some anomalies, provided a sound framework for the whole of chemistry.

Finally in the twentieth century, a more fundamental periodicity was discovered in the electronic configuration of the elements.

Further Notes

Combining weights and atomic weights

Until recently, the determination of atomic weights was based on measurement of the weights of elements that combine with each other, plus a knowledge of the number of atoms of each kind that combine to form one molecule. For example, eight grams of oxygen combine with one gram of hydrogen to form nine grams of water. If it is assumed (as John Dalton assumed) that one atom of oxygen combines with one atom of hydrogen to form one molecule of water, then it appears that the atomic weight of oxygen relative to hydrogen is eight. If, however one atom of oxygen combines with *two* atoms of hydrogen to form one molecule of water, then the atomic weight of oxygen relative to hydrogen is sixteen.

In the mid-nineteenth century, analytical procedures could give very accurate combining weights, but there was still much uncertainty, or disagreement, about the number of atoms in some molecules, for example, the oxides of nitrogen and the oxides of iron. This led to disagreement over atomic weights which could be wrong by factors of 3/2, 2, 3 etc. This would obviously upset any ordering of elements based on atomic weights.

Odling's Table of the Elements (1865)

								Mo	96			W	184		
									–			Au	196.5		
								Pd	106.5			Pt	197		
L	7	Na	23		–			Ag	108		–				
G*	9	Mg	24	Zn	65			Cd	112			Hg	200		
B	11	Al	27		–				–			Tl	203		
C	12	Si	28		–			Sn	118			Pb	207		
N	14	P	31	As	75			Sb	122			Bi	210		
O	16	S	32	Se	79.5			Te	129				–		
F	19	Cl	35.5	Br	80			I	127				–		
		K	39	Rb	85			Cs	133						
		Ca	40	Sr	87.5			Ba	137						
		Ti	48	Zr	89.5				–						
		Cr	52.5		–			V	138			Th	231		
		Mn	55												

Newlands' Table of Atomic Numbers (1865)

H	1	F	8	Cl	15	Co & Ni	22	Br	29	Pd	36	I	42	Pt & Ir	50
Li	2	Na	9	K	16	Cu	23	Rb	30	Ag	37	Cs	44	Tl	53
G*	3	Mg	10	Ca	17	Zn	25	Sr	31	Cd	38	Ba & V	45	Pb	54
Bo	4	Al	11	Cr	19	Y	24	Ce & La	33	U	40	Ta	46	Th	56
C	5	Si	12	Ti	18	In	26	Zr	32	Sn	39	W	47	Hg	52
N	6	P	13	Mn	20	As	27	Di & Mo	34	Sb	41	Nb	48	Bi	55
O	7	S	14	Fe	21	Se	28	Ro & Ru	35	Te	43	Au	49	Os	51

** G is an earlier symbol for beryllium, Be.*

RADIO UNIT 9

Pre-broadcast Notes

Subject
Acids, Alkalis and Salts
Speakers
Dr D. Johnson
Mr S. Barrett

The programme is a talk by Dr David Johnson of the Open University about development of the concepts acid, alkali and salt.

For simplicity, modern chemical names such as sodium chloride or sulphuric acid are used instead of the old fashioned terminology. It is quite important to remember that at the time mentioned, these ideas of chemical formulae and composition did not exist. Sulphuric acid, for example, conveys ideas about chemical composition that 'oil of vitriol', the more ancient name, does not. If you can remember that, you will be better equipped to understand the difficulties of the older chemists.

Post-broadcast Notes

Below is a chronological chart, so you can refer back to details mentioned in the programme.

ca. 3000-2500 B.C.	The Sumerians of Ur used alkalis obtained from plant and wood ash to make soap. The Egyptians embalmed bodies using crude sodium carbonate.
ca. 450 B.C.	Herodotus visited Egypt and described the uses of salt and sodium carbonate as preservatives.
ca. 900 A.D.	The Persian, al-Razi, divided substances into six classes, one of which was 'salts'. The salts included the alkalis obtained from wood and plant ash (sodium and potassium carbonate).
ca. 1300 A.D.	Works attributed to the alchemist, Geber, emphasize the solubility of 'salts'.
ca. 1530 A.D.	Paracelsus (1493-1541) raised 'salts' to a position of great intellectual importance, in his three principles, and emphasized their fixity and incombustibility.
ca. 1660 A.D.	Sylvius de le Boe (1614-72) suggests that the acid-alkaline balance in the body is the secret of good health, and that excesses can be corrected by neutralization reactions. Tachenius (ca. 1620-99) states that salts are made up of an acid and an alkali. Glauber (1604-70) describes neutralization reactions in which salts are formed.
ca. 1680 A.D.	Lemery (1645-1715) interprets acid and alkaline behaviour with a mechanical corpuscular model.

The quotations from the works of Glauber refer to the reaction:

$$K_2CO_3(aq) + 2HNO_3(aq) \longrightarrow 2KNO_3(aq) + CO_2(g) + H_2O$$

You are not expected to remember any names or dates from this programme. The important feature to pick out is the empiricism of the development of the concepts, and the inductive nature of the reasoning involved.

RADIO UNIT 10

Pre-broadcast Notes

Subject

The Development of Penicillin Drugs and the Potential of Computers in Molecular Design.

Speakers

Dr R. R. Hill
Mr F. P. Doyle

In the first part of this Unit's radio programme you are going to hear of the scientific factors which influenced the thinking behind the development of penicillin drugs from the original discovery in 1928 to the present day. The second part will be devoted to the problem of molecular design in such areas as drug research, where our understanding of the actual function of the product is inadequate for it to be designed from first principles.

You should have completed your reading of the main text before listening to the broadcast and, in particular, have the contents of Section 10.6 fresh in your mind.

The actual discovery of penicillin makes fascinating reading, but will not be described in the programme. Briefly, it was made by Professor Alexander Fleming in 1928 whilst conducting research on bacteria. One of his culture plates became fortuitously contaminated by the common mould *Penicillium notatum* and he noticed that, despite the presence of nutrients, the bacteria did not flourish in the neighbourhood of this growth. The mould was isolated, and further investigation established that it produced a substance which prevented the growth of many common bacteria that infect man, but was not toxic to human cells. It had no effect on many other types of bacteria. The release of the antibacterial substance by the mould is still the basis of all commercial production of penicillin, the process being one of *fermentation.*

More detailed accounts of the history and development of penicillin are given in *Encyclopaedia Britannica* and *Chambers's Encyclopaedia.* These references also serve as good background material to the radio broadcast.

The main speaker in the programme, Peter Doyle, heads a team at Beecham Research Laboratories which for many years has been making major contributions to the development of penicillin therapy. Before you listen to his story, you may find it helpful to know the meaning of some of the terms which he will be using. They are:

'zone of inhibition against certain bacteria' – an area where bacteria will not grow;

'gram-positive' and 'gram-negative' – refers to the reaction of bacteria to a dye called Gram's stain. The reactions differentiate between the gram-positive bacteria, which take the stain, e.g. *Staphylococcus, Streptococcus,* and others (gram-negative) which do not, e.g. typhoid bacteria;

'penicillinase' – an enzyme which destroys penicillin;

'allergy' – an adverse clinical reaction in response to the presence of a particular substance;

'polymerize' – the chemical union of molecules of the same compound to form larger molecules (discussed in detail in Unit 13);

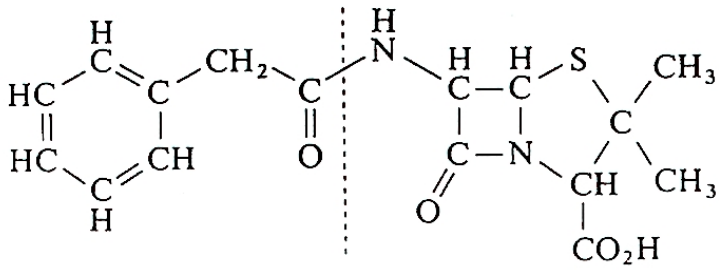
'bacterial cell wall' – a cell is a living sub-unit of all organisms (discussed in detail in Unit 14);

'mutation and natural selection' – inherent changes in characteristics of a biological species which are established by adaptation to a new environment (discussed in detail in Unit 19).

You are also provided with display sheets of structural formulae which you should have in front of you when listening. The speaker will pause for a few seconds every time one is mentioned for the first time. They

Text continued on p. 17.

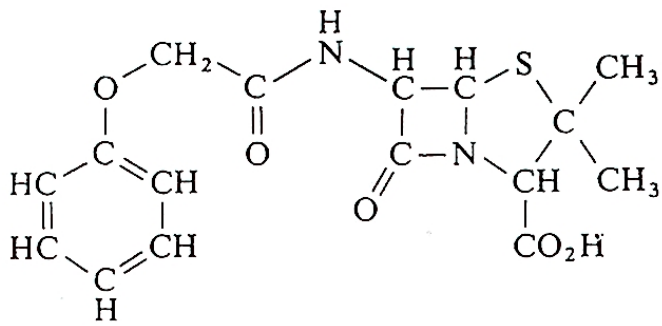
Display Sheets for Radio Unit 10



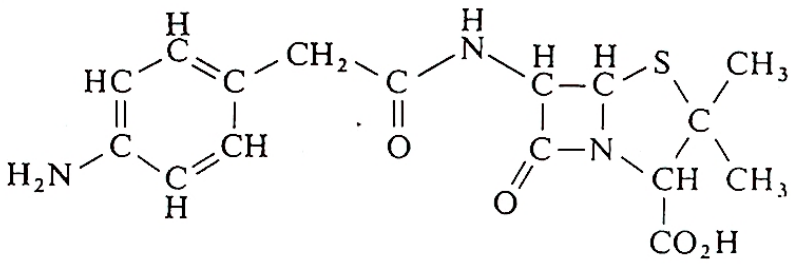
phenylacetyl side chain

'nucleus'

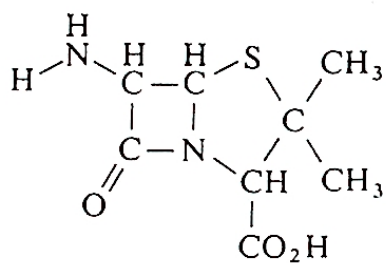
penicillin G



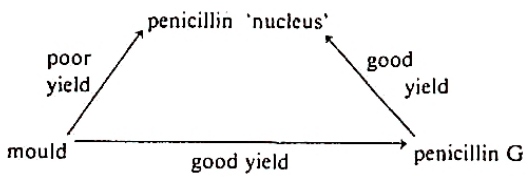
penicillin V

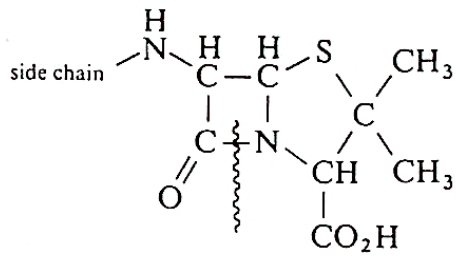


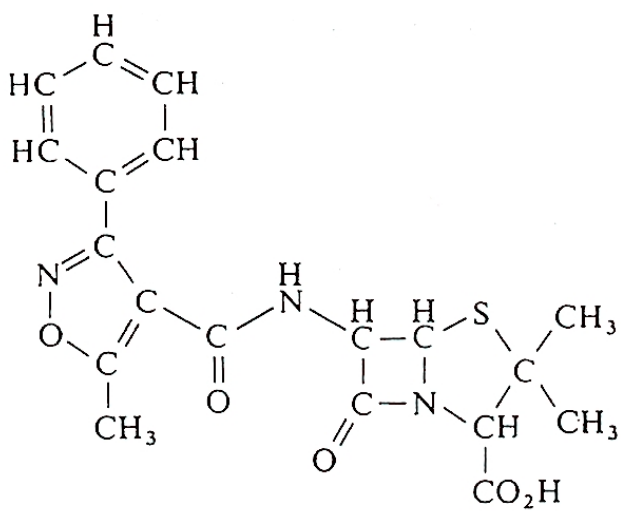
penicillin with amino group in side chain



penicillin 'nucleus'







modified penicillin which is resistant to the enzyme penicillinase

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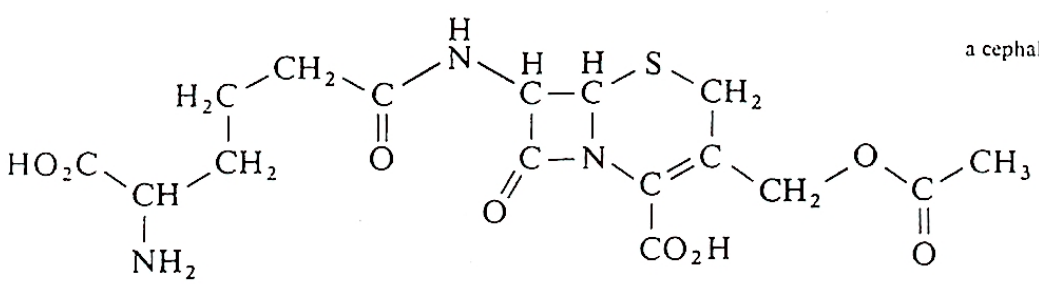
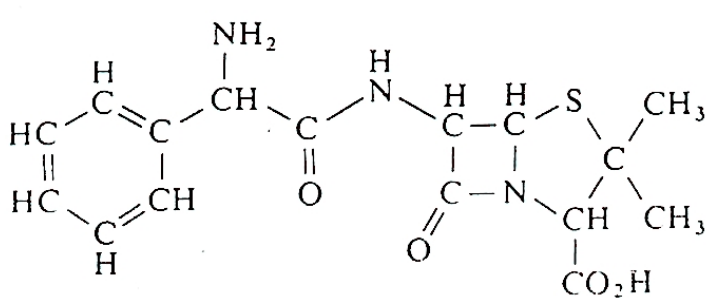
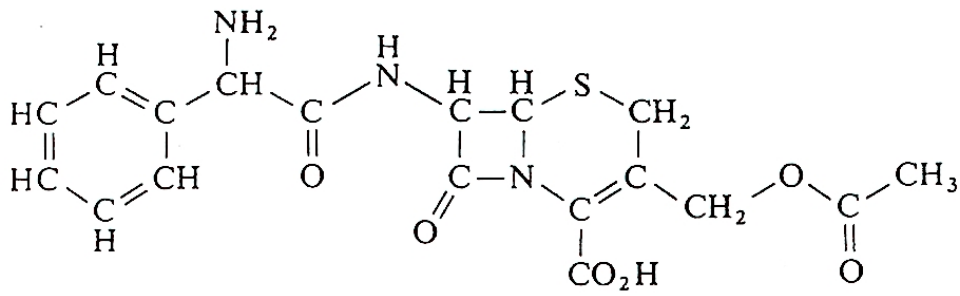


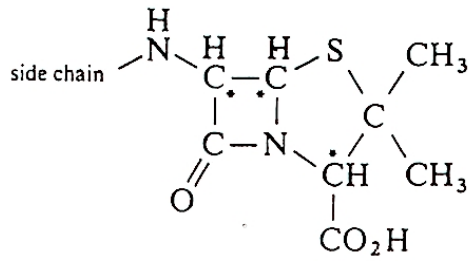
a cephalosporin — Cephalosporin-C



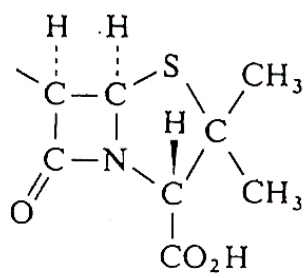
ampicillin — active against gram-negative organisms



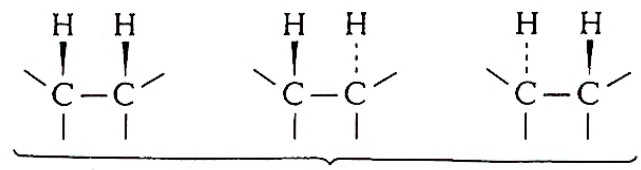
cephalosporin antibiotic
analogous to ampicillin



* chiral centres



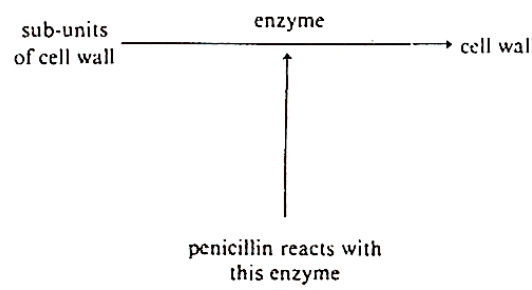
actual relative
geometry



alternative relative
geometries

▌coming up from the plane of the paper

: going down behind the plane of the paper



$H_2N-CH_2-CH_2-OH$

β-hydroxyethylamine

atom connectivity table

1	N	–	–
2	C	1	1
3	C	1	2
4	C	1	3

chemical notation

Z2Q

are written in 'order of appearance' so you should have no difficulty in locating them on the sheet as they come up. Nevertheless, you are strongly recommended to glance through them and the wording of the captions shortly before the broadcast. You are not expected to remember the chemical structures and their names.

During the talk, reference is made to a type of chemical reaction which is particularly useful in 'molecule building', that is, chemical synthesis. In fact you have met it already in the text. It concerns the amino group, $-NH_2$, which can react with molecules of the type $R-\overset{\overset{O}{\|}}{C}-X$, where R is an organic structural fragment and X is an electronegative atom or group. (R could be very simple such as $-CH_3$ or a highly complex group of carbon and other atoms. X could be $-Cl$ — OH, $-OCH_3$, etc.) The synthetic reaction can be formulated:

$$R-\overset{\overset{O}{\|}}{C}-X + H_2N-R^1 \longrightarrow R-\overset{\overset{O}{\|}}{C}-NH-R^1 + HX$$

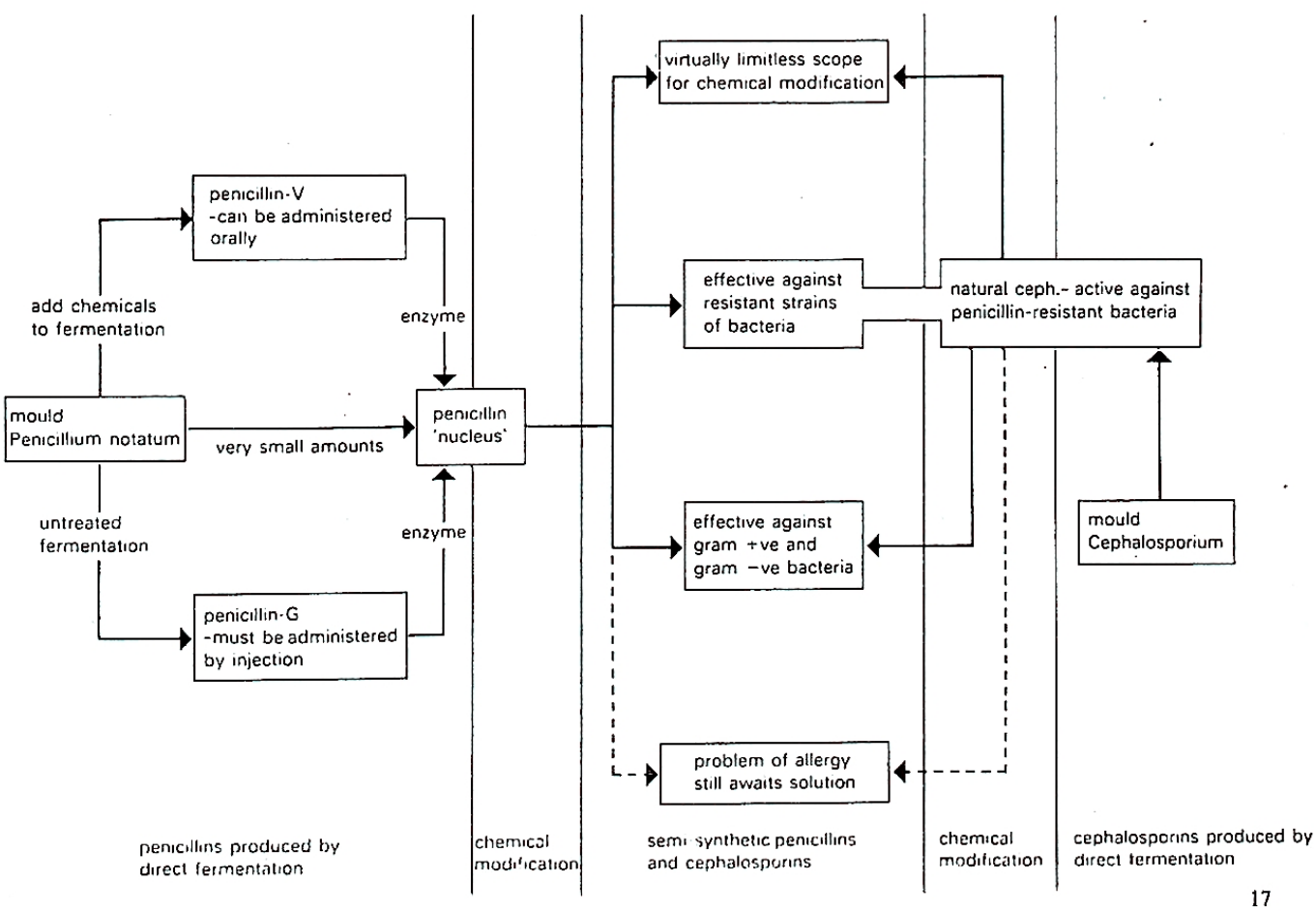
where R^1 is another organic structural fragment.

The last illustration given in the display sheet refers to the second part of the programme. Do not worry about the detail here, or even what it means. The diagram is there to give you an idea of the kind of symbolism that is used. We refer to it in the broadcast as a 'linear representation', that is, an array of figures and letters which can be assimilated by a computer.

Post-broadcast Notes

The account of penicillin development which you heard is summarized in a conceptual diagram (Fig. 1).

Figure 1 Summary of the Development of Penicillins and Related Antibiotics


virtually limitless scope for chemical modification
penicillin-V -can be administered orally
add chemicals to fermentation
enzyme
effective against resistant strains of bacteria
natural ceph.- active against penicillin-resistant bacteria
mould Penicillium notatum
very small amounts
penicillin 'nucleus'
untreated fermentation
enzyme
effective against gram +ve and gram −ve bacteria
mould Cephalosporium
penicillin-G -must be administered by injection
problem of allergy still awaits solution
penicillins produced by direct fermentation
chemical modification
semi-synthetic penicillins and cephalosporins
chemical modification
cephalosporins produced by direct fermentation

The essential point to remember from the last part of the programme is the potential power of a computer-based structure/property storage and retrieval system to predict structures of compounds which would possess a given set of properties. Computers can already 'draw' chemical formulae (Fig. 2). Such a system would be of immense value to areas of technology which rely, and will have to rely for some time, on empirical information for the development of new materials for specified purposes.

Figure 2

RADIO UNIT A

This will be a feedback programme. The notes associated with this programme will be sent to you in a separate mailing.

RADIO UNIT 11

This will be a feedback programme. The notes associated with this programme will be sent to you in a separate mailing.

RADIO UNIT 12

Pre-broadcast Notes

Subject
The Importance of Reaction Theory in Industrial Processes

Speakers
Dr R. A. Ross
Dr D. A. Johnson

In this radio programme we have set out to give you an idea of the practical importance of the theory contained in Units 11 and 12. In the programme Dr Ross and Dr Johnson will discuss examples of industrial processes where the knowledge of reaction theory was essential to the achievement of economic yields.

You will find below an outline of the concepts which will be covered in the broadcast. It is important that you should have a general understanding of these concepts before listening to the broadcast. All of them are described in the texts of Units 11 and 12.

The display sheet lists the equations etc. which will be referred to in the broadcast. You will note that some of the equations are repeated; this is simply to reduce the amount of back reference. You should look through the display sheet before the broadcast so that you are familiar with its contents (p. 20).

Outline of Topics from Units 11 and 12 covered in Broadcast

There are two basic types of energy consideration in a reaction.

1 Activation Energy, E‡

This is the basic constraint on the rate of reaction and thus the rate constant, k, at any particular temperature. *The temperature*, however, determines the average energy of the reactants and is the other basic factor which controls the rate of reaction. Increasing the temperature will always increase the rate of reaction.

2 Enthalpy Change ΔH

The enthalpy change or heat of reaction is the energy change that accompanies a reaction. If energy is released to the surroundings then ΔH is negative and the reaction is said to be exothermic. If energy is withdrawn from the surroundings then ΔH is positive and the reaction is said to be endothermic.

3 The Equilibrium Constant

When a reaction is at equilibrium the relationship between the concentrations of the reagents is given by the equilibrium constant. The way K varies with temperature is determined by the enthalpy change for the reaction. If ΔH is positive (reaction endothermic) K increases with temperature. If ΔH is negative (reaction exothermic) K decreases with temperature.

Display Sheet for Radio Unit 12

$$Fe_2O_3 + 3CO \rightleftharpoons 2Fe + 3CO_2 \quad (1)$$

$$2C + O_2 \rightleftharpoons 2\,CO$$

$$C + O_2 \rightleftharpoons CO_2$$

$$\Delta H^{\theta}(298K) = -393.5\ kJ\ mol^{-1} \quad (2)$$

Table 1

Temperature (°C)	% Composition of product	
	CO	CO_2
450	2	98
750	76	24
1050	99.6	0.4

$$2C + O_2 \rightleftharpoons 2CO \quad (3)$$

$$2C + \underbrace{O_2 + 4N_2}_{\text{air}} \rightleftharpoons \underbrace{2CO + 4N_2}_{\text{producer gas}} \quad (4)$$

$$2C + O_2 + 4N_2 \rightleftharpoons 2CO + 4N_2$$

$$\Delta H^{\theta}(298K) = -221.0\ kJ\ mol^{-1} \quad (5)$$

$$C + H_2O \rightleftharpoons \underbrace{CO + H_2}_{\text{water gas}}$$

$$\Delta H^{\theta}(298K) = +131.3\ kJ\ mol^{-1} \quad (6)$$

Table 2

Temperature °C	% Steam decomposed	% Composition of Product		
		H_2	CO	CO_2
674	8.8	65.2	4.9	29.8
1 010	94.0	48.8	49.7	1.5
1 125	99.8	50.9	48.5	0.6

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

$$\Delta H^{\theta}(298K) = -92.4\ kJ\ mol^{-1} \quad (7)$$

Nitrogen from Producer Gas

$$\underbrace{2CO + 4N_2}_{\text{producer gas}} + \underbrace{O_2 + 4N_2}_{\text{air}} \longrightarrow 2CO_2 + 8N_2$$

$$2CO_2 + 8N_2 + \underbrace{2CaO(s)}_{\text{lime}} \longrightarrow 2CaCO_3(s) + 8N_2 \quad (8)$$

Hydrogen from water gas

$$\underbrace{CO + H_2}_{\text{water gas}} + H_2O \xrightarrow[\text{catalyst}]{FeO} CO_2 + 2H_2$$

$$CO_2 + 2H_2 + CaO \longrightarrow CaCO_3 + 2H_2 \quad (9)$$

4 Catalysis

A catalyst changes the mechanism of a reaction. The catalysed mechanism has a lower activation energy and results in a faster rate. A catalyst does not change the overall reaction and hence cannot alter the enthalpy change or the equilibrium constant. Both forward and reverse reactions have their rates increased.

5 Le Chatelier's Principle

This deals with the effect of varying the conditions (temperature, pressure, volume and concentration) on the equilibrium position.

A temperature increase will disturb the equilibrium so as to reduce the temperature (i.e. favour the endothermic process).

A pressure increase will disturb the equilibrium so as to reduce the pressure (i.e., favour that process which reduces the number of molecules present and thereby the pressure).

Post-broadcast Notes

The broadcast which you heard dealt with two main examples taken from industry:

1 the Producer-Gas/Water-Gas Process;

2 the Haber Process.

The essential points can be summarized as follows:

1 Producer-Gas is formed from air and coke by an exothermic process. This means that the reaction heats the coke and that the gas formed is very hot. This energy can be used efficiently by burning the gas locally to heat coal to produce coke, tar and coal gas. However, if the gas is allowed to cool it looses most of its useful energy. This is because only a third of it is combustible (CO), the rest is nitrogen.

Water-Gas is formed from steam and coke and is a mixture of hydrogen and carbon monoxide both of which burn in air to release large quantities of heat. It is therefore a good gas for use in the domestic gas system (Town Gas) in addition to coal gas. However, water gas is formed by an endothermic process and so its formation cools the coke, but to get good conversion it is necessary that the temperature of the coke be maintained above 1 000 C. This is achieved by producing both gases alternately in the same reactor: the heat required to keep the coke temperature above 1 000°C for the Water-Gas process is supplied by the intermittent formation of Producer Gas. An alternative procedure is to produce both gases simultaneously, adjusting the inputs of air and steam to ensure a reaction temperature in excess of 1 000 °C. The product is called semi-water gas. The discovery, and large scale use, of natural gas in the North Sea is resulting in the dropping of these processes as far as their use in producing Town Gas is concerned.
The points you should remember from this example are:

(i) The minimum reaction temperature for efficient yield, see Tables I and II.

(ii) The balancing of the energy requirements of the endo- and exothermic processes to give an energetically self-sufficient industrial process.

2 The Haber Process is the formation of ammonia from hydrogen and nitrogen, both of which are very plentiful, and can in fact be obtained from water-gas and producer-gas respectively. However, the process while

basically simple presented a problem. This was that the temperature condition required to increase the reaction rate was diametrically opposed to that required to produce a favourable equilibrium, since the formation of ammonia is an exothermic reaction. The dilemma was solved by reducing the temperature necessary to obtain an economic reaction rate by using a catalyst. The equilibrium was pushed in favour of ammonia by increasing the pressure, thus taking advantage of the decrease in molecularity that accompanies the reaction (4 mole ——→ 2) (le Chatelier's Principle).

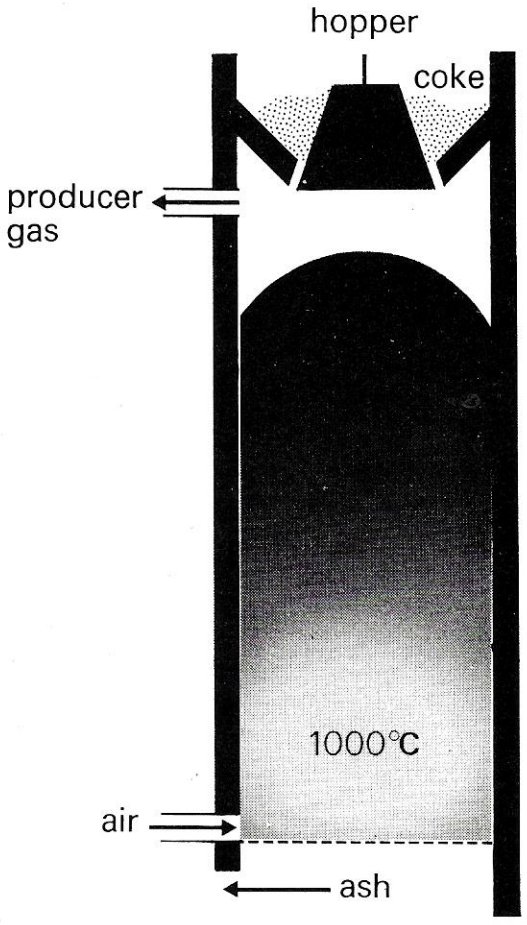


Figure 1 Producer-Gas Furnace (Producer).

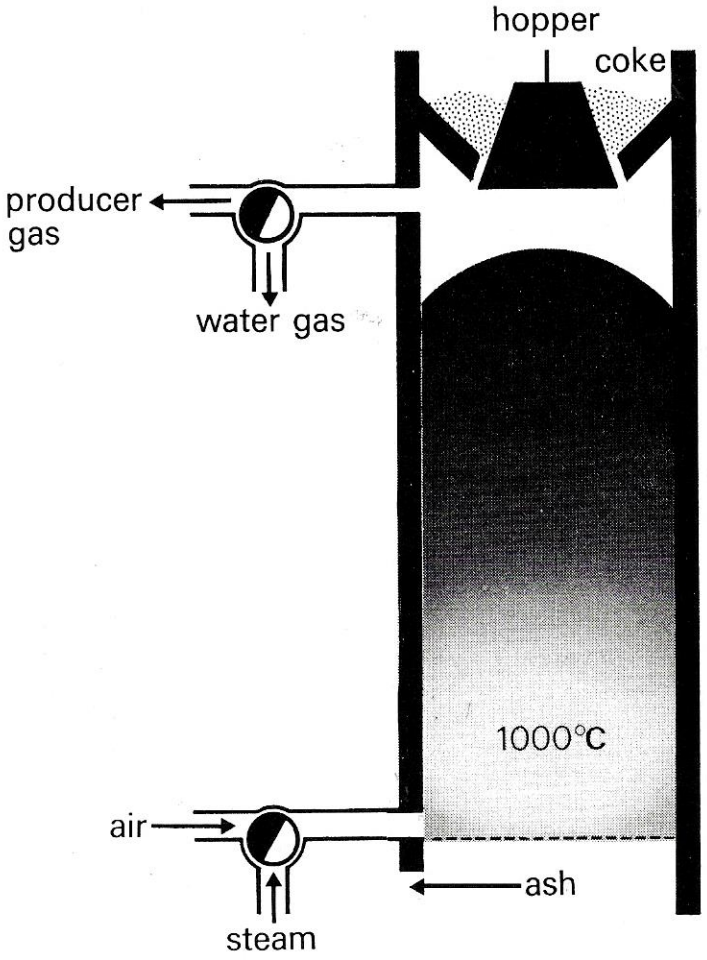


Figure 2 Water-Gas Furnace.

RADIO UNIT 13*

Pre-broadcast Notes

Subject
Giant Molecules

Speakers
Professor L. J. Haynes
Dr R. R. Hill

Unit 13 is now a 'black-page' Unit. However, simply turning a Unit black would have left a hole in an otherwise integrated Course. So this radio programme is intended to bridge the gap between the essentially chemical and essentially biological parts of the Course. You will see that we have included some *SAQ*s in the post-broadcast notes to help you find out whether you have 'crossed the bridge'. However you will not be assessed on this material directly, either in continuous assessment, or in the examination. But you will find that it does help your understanding of some topics in Units 14–19. The topic we have chosen is Giant Molecules, but the programme will *not* be an audio version of Unit 13! It concentrates on biological giant molecules, chiefly carbohydrates and proteins. The Objectives are as follows.

** Please note that there are two sets of notes which refer to Radio Unit 13. This first set refers to the programme which you will be able to listen to on the radio. The second set refer to a programme which is only available on tape at your study centre.*

When you have heard the broadcast and studied the broadcast notes you should be able to:

1 State whether a given molecular structure of a section of a giant molecule

(i) is a polymer, or
(ii) contains repeating units of the same type, but is not a polymer, or
(iii) does not contain repeating units.

2 Identify the repeating unit in a giant molecule of types (i) and (ii) above.

3 Distinguish between correct and incorrect representations of general structures for a polysaccharide and for a protein.

4 Identify features common to both starch and cellulose and those special to each.

5 Write down the structure of a polypeptide chain given the structures of the constituent amino acids and their sequence in the chain.

6 Distinguish between statements referring to the primary structure of a protein and those referring to its secondary structure.

Meeting these Objectives will be of considerable assistance to you in forthcoming Units. You will notice that the Study Guide to Units 14–16 advises you to read certain sections of the *Chemistry of Life* before you start to study Unit 14. Some of these sections form part of the post-broadcast notes for this programme.

The speakers will be referring to diagrams during the broadcast. These are all taken from books you have already, and you should have them open and ready before the broadcast begins. (Sheets of paper inserted between appropriate pages will help you find them quickly.) The diagrams, in order of reference, are:

Diagram 1 Unit 10, Figure 15, p. 33

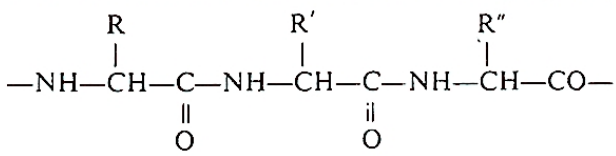
Diagram 2 Unit 13, all the structures on p. 9

Diagram 3 Unit 13, the structures at the top of p. 12

Diagram 1 (repeat)

Diagram 4 Unit 13, the structures of amylose and amylopectin, p. 33

Diagram 5



You should look at these briefly before the programme and also re-read Section 10.4.4 of Unit 10.

Post-broadcast Notes

Use as post-broadcast notes, Unit 13, Section 13.1, *Chemistry of Life* by Steven Rose pp. 45–52 and pp. 56–69.

Self-assessment Questions

Question 1 (*Objectives 1 and 2*)

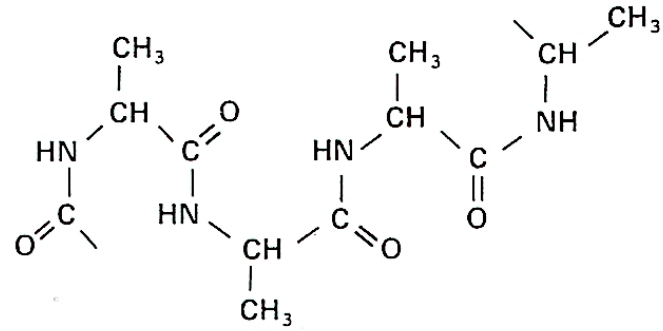
For each of the structures I and II, state whether

(i) it represents part of a polymer;

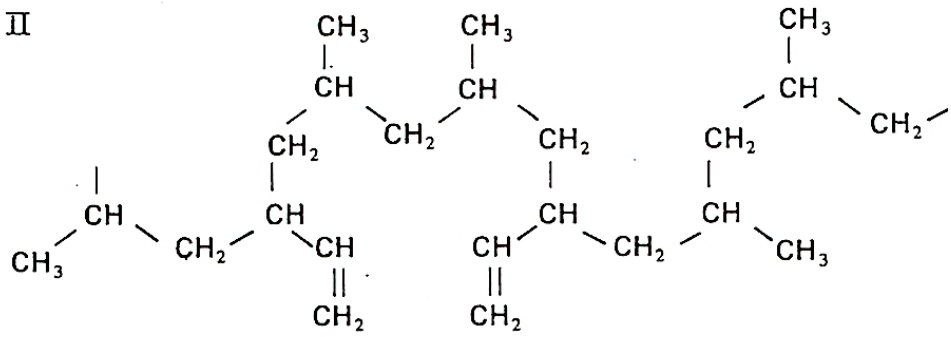
(ii) it is not strictly a polymer but a molecular chain where the same *type* of unit is repeated;
(iii) it is neither (i) nor (ii).

If you chose (i) or (ii) for either structure draw the repeating unit or the type of repeating unit involved.

I



II



Question 2 (*Objective 3*)

(i) Which of the following structures can be said to represent schematically the general structure of a protein?

III -NH - C - A - C - NH - B - NH - C - A - C - NH - D - NH - A - NH -

IV - NH - C - A - NH - C - A - NH - C - A - NH - C - A - NH - C - A -

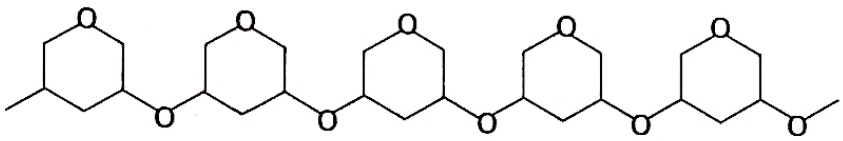
V - N - C - N - C - N - C - N - C - N - C - N - C -
A B A D A B

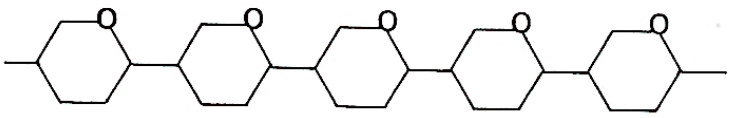
VI - NH - C - A - NH - C - B - NH - C - D-NH - C - A - NH - C -

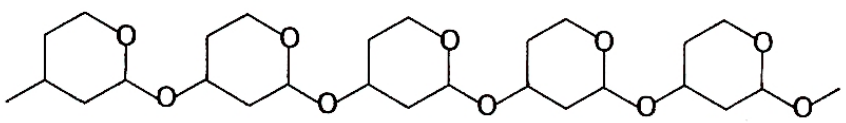
VII - C - NH - A - C - NH - B - C - NH - D - C - NH - A - C - NH -

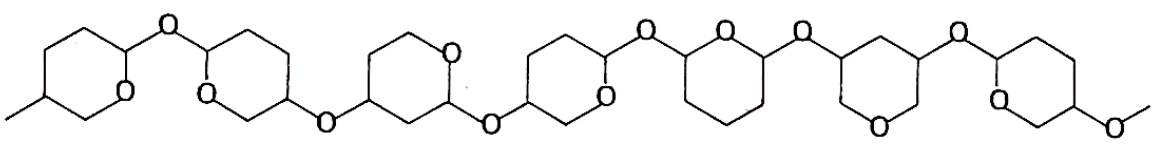
Where A, B and D are hydrocarbon fragments.

(ii) Which of the following structures best represents schematically the general structure of a polysaccharide?

VIII 

IX 

X 

XI 

Question 3 (*Objective 4*)

Classify each of the items (i)–(vi) as being:

A true for starch but untrue for cellulose

B true for cellulose but untrue for starch

C true for both starch and cellulose

D true for neither starch nor cellulose

(i) Can be hydrolysed to pure glucose.

(ii) Serves as a food store for plants.

(iii) Fulfills a structural role in most animals.

(iv) Contains branched chains.

(v) Contains $-CH_2-OH$ groups.

(vi) The oxygen link is on the same side of the six-membered ring as the $-CH_2OH$ group.

Question 4 (*Objective 3*)

If you have not already done so, try the exercise at the end of the protein Section of Unit 10 (Section 10.4.4).

Question 5 (*Objective 6*)

Indicate whether each of the following statements refers to the primary or the secondary structure of a protein.

(i) All but one of the amino acid units are chiral.

(ii) Slight changes in pH can alter the properties of a protein.

(iii) Disulphide bridges can be formed between cysteine units in a protein.

(iv) The biological function of a protein can be drastically affected by the absence of one particular amino acid unit.

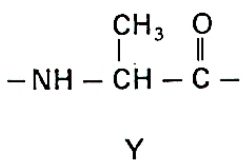
Self-assessment Answers and Comments

Question 1

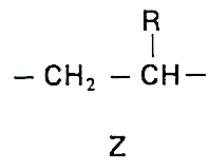
Answer (i) I; (ii) II.

Comment

Free rotation about single bonds allows a chain of such bonds to twist and turn to virtually any shape. So ignore the over-all shapes of these fragments and concentrate on their constituent parts. You will see that I is a polymer with a repeating unit Y



Y



Z

R = CH_3 or $CH{=}CH_2$

and II has a repeating unit with one variable component (Z).

Question 2

Answer (i) (VI) and (VII); (ii) (X).

Comment

(i) (III) is incorrect because although the groups A, B and C are connected by amide links there is no head to tail sequence (see Unit 13, p. 12).

(IV) is unlikely because it implies a whole stretch of protein made up from one amino acid alone.

(V) see Unit 13, p. 12.

Both (VI) and (VII) are acceptable.

(ii) A polysaccharide must have oxygen links between the rings and this link must connect with a C—O bond in at least one of the rings on either side. Any one section must show a regularity in structure.

Question 3

Answer (i) C; (ii) A; (iii) D; (iv) A; (v) C; (vi) B.

Comment

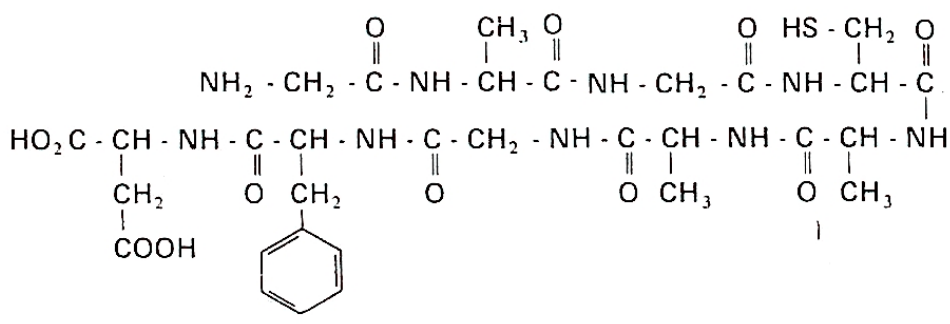
(i)-(iv) see *Chemistry of Life* pp. 50, 51.

(v) These are present in glucose and are left intact in most units in both polysaccharides.

(vi) See Unit 10, Section 10.4.4 and Unit 13, p. 33.

Question 4

Answer



Comment

This is one of two structures which are possible. The other involves starting with a free $—CO_2H$ group rather than a free $—NH_2$ group. See *Chemistry of Life*, p. 62, centre paragraph.

Question 5

Answer (i) (iv), primary; (ii) (iii), secondary.

Comment

(i) and (iv) concern the structure of the chain irrespective of the shape it adopts.
(ii) and (iii) affect the over-all shape of the protein. See *Chemistry of Life*, pp. 63–9.

RADIO UNIT 13

Pre-broadcast Notes

This week's programme deals with the discovery and development of polythene. The programme can be divided into four parts.

1 Professor Haynes introduces the programme by describing the background which led up to the discovery of polythene by Dr R. O. Gibson and E. W. Fawcett on 27 March, 1933. Dr Gibson himself explains how he came to meet Dr A. Michels in Amsterdam, who subsequently supplied I.C.I.'s laboratory in Winnington with the equipment for high pressure experiments. It was this work which led to the discovery.
2 Mr E. G. Williams, the present Chairman of I.C.I. Plastics Division, Welwyn, recalls the experiment he performed in which polythene was first made in appreciable quantities.
3 Then Dr E. Hunter, who in 1936 was put in charge of the technical development of the process, describes the difficulties of the process and also how market factors influenced polythene production.
4 Professor Haynes winds up the programme with a look at the growth of polythene production since the Second World War.

The aim of this programme is to give you an idea of how a major chemical product (polythene) comes about, and of the factors that influence its discovery, development and production. You should not worry too much about the names and dates mentioned in the broadcast; there is a list of the more important ones in the post-broadcast notes.

The following terms will be used in the broadcast:

dielectric – in this context, another word for an electrical insulator.
electrical resistivity – this is a measure of the resistance of a material to the passage of electricity. Its value depends on the frequency of the alternating current of the electrical signal. A signal with a high frequency can more easily be dissipated through the insulator. For example, in a long insulated wire, such as in a telegraph cable of several hundred miles length, the loss of high-frequency signal may be so great that no signal reaches the end. This can only be improved by using an insulator which is a better dielectric for high frequencies.

gutta-percha – this is a rubber-like substance which was used as an insulator in telegraph cables before 1939. However, it has two big drawbacks. Firstly, it is a jungle product and the trees which produce it were not grown on plantations. Furthermore, when they are tapped the trees die – unlike rubber trees. Secondly, while it has good low-frequency insulation properties, it does not have a very good high-frequency performance.

NOTE

The radio programme to which these notes refer will not be broadcast by the BBC; but the programme is available on tape for listening to at study centres.

Subject

The Discovery and Development of Polythene

Speakers

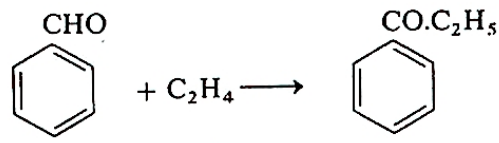
Professor L. J. Haynes
Dr R. O. Gibson
Dr E. Hunter
Mr E. G. Williams

The data in Table 1 will be referred to during the programme. You should make yourself familiar with them before the programme.

Post-broadcast Notes

1 Professor Haynes gave a brief account of the background to the discovery of polythene. The most significant part was the setting up at Winnington by F. A. Freeth of a research section for long-term research on the more important branches of chemistry and physics.

Dr R. O. Gibson then took up the story, showing how his personal acquaintance with Dr A. Michels and his high-pressure work at the Thermodynamics Laboratory of the University of Amsterdam led to the study of chemical reactions under high pressures at Winnington. It was on 27 March, 1933, while studying the reaction between ethylene and benzaldehyde at 2 000 atmospheres and 170°C, that Gibson and Fawcett first made polythene. Gibson and Fawcett had hoped that the following reaction would occur:



benzaldehyde ethylene

However, investigation of the new material was abandoned, partly because the amounts yielded by the experiments were so small (less than 0.1 g) and partly because of the danger of explosion.

2 Mr E. W. Williams then explained how the work on polythene re-started in late 1935 using new all-steel apparatus. Now, about 5 g of polythene were obtained, and it was at this point that polythene was found to be a very good insulator, especially for high-frequency signals.

The reason for the success of this second series of experiments was probably because the steel apparatus conducted away the heat of the reaction and thus avoided the decomposition of the polythene, which had been formed, to carbon and hydrogen. (The reaction chamber in Gibson's apparatus was almost completely glass.)

3 Dr E. Hunter, who in 1936 was put in charge of the semi-technical development of polythene, explained how the process had to be improved by controlling the reaction temperature, so that the decomposition reaction could be prevented, and by making the process continuous. One of the most notable facets of this development was its dependence on the help of Dr Michels – particularly in designing a continuous high-pressure pump. As Dr Hunter said '. . . the development of polythene and its subsequent large-scale production depended on a highly unconventional laboratory pump designed by a physicist (Michels) for use by physical chemists'. The initial industrial development of polythene was spurred on by its potential use in submarine cables in place of gutta-percha, but no sooner had industrial plant been built than war broke out and polythene became essential as the only material with good enough insulating properties for use in radar.

The great upsurge in polythene production caused by the Second World War can easily be seen from Table 1. One should remember, here, that

world production meant initially that of Britain, but by 1945 world production was shared equally by Britain and the U.S.A.

4 The growth of polythene production since the War is also clearly shown in the Table. The introduction in the late 1950s of 'low-pressure' polythene, made by a process involving Ziegler catalysts,* was a significant development. This material has different properties from 'high-pressure' products and has extended the market in polythene. The production of both types of the polymer continues to rise.

Names and Dates

Dr R. O. Gibson and E. W. Fawcett – Discovered polythene, 27 March 1933.

E. G. Williams – Performed experiment in which polythene was first made in a reasonable quantity, 20 December, 1935.

Dr A. Michels – Dutch physicist who designed and supplied the first high-pressure equipment. High-pressure pumps of his novel design were used up till 1950.

Table 1 World polythene production

Period	Production
1933–37	30 lb
1933–38	1 ton
1945	7–8 000 ton
1950	30 000 ton
1954	100 000 ton
1958	400 000 ton
1962	1 000 000 ton

1970 estimate of 1973 World Production: 10 million tons

RADIO UNIT 14

Subject
Biology
Speakers
Professor Steven Rose
Dr Robert Olby

Present-day biology takes for granted not only a set of techniques for the analysis of living material, but also a set of themes concerning its composition. One of the most important of these is cell theory, which states that all living organisms are built up of individual units of defined structure. Cell theory is as fundamental to biology as atomic theory to chemistry, and its development occupied some of the leading biologists of the nineteenth century. Some of the key steps in this development are described in this radio programme. A second major advance in theory, also occurring in the nineteenth century, was the recognition that cells are composed of a relatively small number of types of macromolecule, which can be extracted, purified and studied in isolation. This seems obvious to us today but, like cell theory, did not go unchallenged in the nineteenth or early twentieth century.

You should not attempt to recall the details of the experiments or the names of the experimenters, but the examples given in this programme will be helpful in providing case studies of the interactions between theory, technique and scientific advance.

* *See Section 13.2.2 of the Main Text.*

RADIO UNIT 15

Pre-broadcast Notes

Subject
Cell Dynamics 1

Speakers
Professor Steven Rose
Professor Sir Hans Krebs

One of the key developments of metabolic biochemistry discussed in the Unit is that of the Krebs cycle, the central metabolic whirlpool in which the final stages of the breakdown of glucose and many other substances to carbon dioxide occurs. It is named after its discoverer, Sir Hans Krebs, who has himself been a central figure in biochemistry throughout his career.

In this broadcast, Professor Steven Rose interviews Sir Hans Krebs about the early experiments which led to the *conception* of the cycle and about Sir Hans' recollections of his early life.

He was born in 1900 at Hildersheim in Germany and educated at the Universities of Göttingen, Freiburg, Munich and Berlin. Two of the workers whose ideas influenced his early development, and who are referred to in the broadcast, were Knoop and Warburg. His early work was carried out in Otto Warburg's laboratory. He left Germany in 1933, having been forced to give up his position by the Nazis, and came to England to work in Sir Frederick Gowland Hopkins' biochemistry laboratory in Cambridge. From 1935 to 1954 he worked in Sheffield, being professor there from 1945. In 1954 he was appointed to the chair of Biochemistry at Oxford which he held until he retired in 1967. Since then, he and his staff have set up a new laboratory in the Radcliffe Infirmary where he continues in active research. In 1953, he was awarded the Nobel Prize for the work that led to the development of the 'Krebs Cycle'.

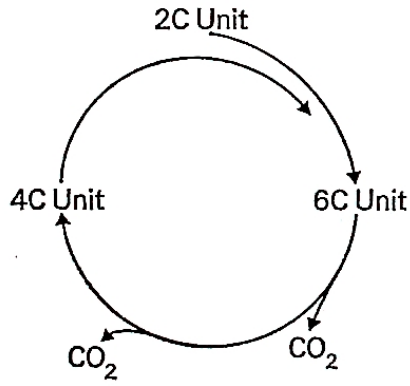
You should familiarize yourself with the principles of the Krebs cycle before listening to this broadcast (*The Chemistry of Life*, pp. 128–34). During the broadcast Sir Hans refers to the following reactions:

$$\text{Glucose} \xrightarrow[\textit{anaerobic breakdown}]{} \text{Lactic acid or Ethanol}$$

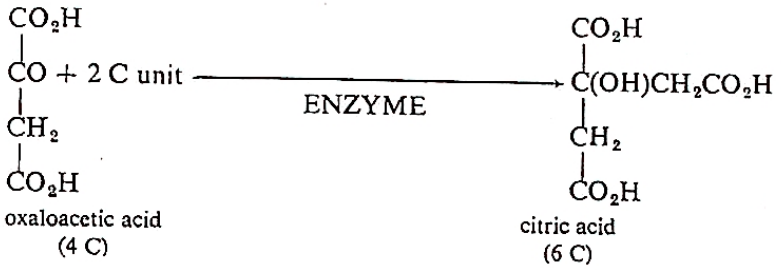
$$\text{Glucose} \xrightarrow[\textit{aerobic breakdown}\ (\textit{oxidative})]{} CO_2 + H_2O$$

Intermediate substances thought to be on the pathway of the aerobic breakdown of glucose to carbon dioxide and water were tested for their ability to cause oxygen uptake when incubated with a tissue such as liver. Amongst those which did become oxidized were citric acid (6 C), succinic acid (4 C) and malic acid (4 C).

Hence the idea was established that di- and tri-carboxylic acids were somewhere involved. But, although citric acid is constantly being broken down, it is also being re-formed in a cyclic process.



It was re-formation of citric acid from oxaloacetic acid, and the demonstration of an enzyme which would do this, which was a key experiment in developing the idea of the cycle.



oxaloacetic acid (4 C)

citric acid (6 C)

You are not, of course, expected to be able to remember the details of these reactions, though you can set them in their context by reading the relevant part of *The Chemistry of Life* (pp. 128–34). You *should* be able to use the material and ideas developed in this programme as one example of the relationship between a scientist's life and work, and the society in which he operates. This theme is taken up again in Unit 34.

RADIO UNIT 16

Pre-broadcast Notes

Subject
The Uses and Abuses of Biochemistry
Speakers
Dr Magnus Pyke
Dr Robert Smith
Professor Steven Rose

In this programme a number of recent and not-so-recent developments in biochemistry which have led to significant technological, and hence social, changes are discussed. The programme introduced by Professor Steven Rose falls into two halves. In the first, Dr Magnus Pyke talks about some positive aspects of developments in biochemistry and the production of new crop strains, foodstuffs and drugs, and the effect this has had on the quality of human life in the industrialized world. Note that Dr Pyke refers to other aspects of biology besides biochemistry: he discusses the application of genetics (Unit 17) and crop breeding (Units 19 and 20) as well as topics derived from the material you have already met in Units 14–16. In the second half, Dr Robert Smith discusses some less beneficial developments, accidental disasters like the thalidomide tragedy, and the deliberate application of biochemistry to the development of weapons – chemical and biological agents.

You need not attempt to recall the names of the particular wheat strains and substances referred to by the speakers, but for reference they are as follows:

Dr Pyke referred to:

the wheat strains: 'Marquis', 'Regent', 'Federation', 'Ceres', '56' and 'Thatcher'

the optical isomers of tartaric acid

the diseases anthrax, rabies, typhoid, scarlet fever, diphtheria, malaria, bilharzia

stem rust – a fungus disease of wheat caused by the organisms P. *graminis* and P. *triticina*

the hormones androgen (male hormone) and oestrogen (female hormone)

Dr Smith referred to:

the poisonous substances:
chlorine, mustard gas, phosgene, and the nerve gases

the mind-affecting substances:
lysergic acid diethylamide (LSD), marijuana, amphetamine and 'BZ'

the pesticides and herbicides:
DDT; 2, 4-D and 2, 4, 5-T

the drugs:
thalidomide and sulphanilamide ('sulpha')

the diseases:
anthrax, plague, tularemia, brucellosis, smallpox, yellow fever, Q-fever, typhus, malaria, sickle-cell anaemia

the micro-organisms:
bacteria, virus, rickettsia, and fungus (plant fungi)

the autonomic nervous system:
– a group of nerves in the body controlling heart beat, breathing, etc., which you will meet again in Unit 18

pathogens: disease causing micro-organisms

chemotherapy: the treatment of disease with drugs

congenital defect: a biochemical or physical deformity with which an individual is born – harelip, cleft palate or phenylketonuria, for example

teratogenic: 'birth-deformity causing' – the effect of the drug thalidomide, for example

genetic code: role of DNA in protein synthesis, discussed in Unit 17

RADIO UNIT 17

Pre-broadcast Notes

Subject
Molecular Biology

Speakers
Sir Lawrence Bragg
Dr J. C. Kendrew
Professor M. R. Pollock

The programme considers briefly the early days of the development of Molecular Biology, with contributions from Sir Lawrence Bragg and Dr John Kendrew, Department of Molecular Biology, Cambridge.

The initial decisions to go ahead and start research into the structure of large biological molecules were taken largely by Bragg; these decisions culminated in the setting up of the Medical Research Council Unit at Cambridge. With the support of the MRC, research workers such as Kendrew and Perutz were able patiently to work out the three-dimensional structure of protein molecules. Other workers in the group included Frederick Sanger, who worked on the primary sequence of insulin, and James Watson and Francis Crick, who concentrated on the structure of DNA. These results laid the foundation for one of today's most exciting areas of science – molecular biology, the subject of Unit 17.

Professor Pollock of the Department of Molecular Biology, Edinburgh University, himself involved in some of the seminal work on the mechanisms of the *regulation* of protein and enzyme synthesis, discusses the importance of a scientist asking the right questions and of having the right biological tools and techniques available to make his experiments.

Pre-broadcast Notes

Subject
Control, Brains and Computers

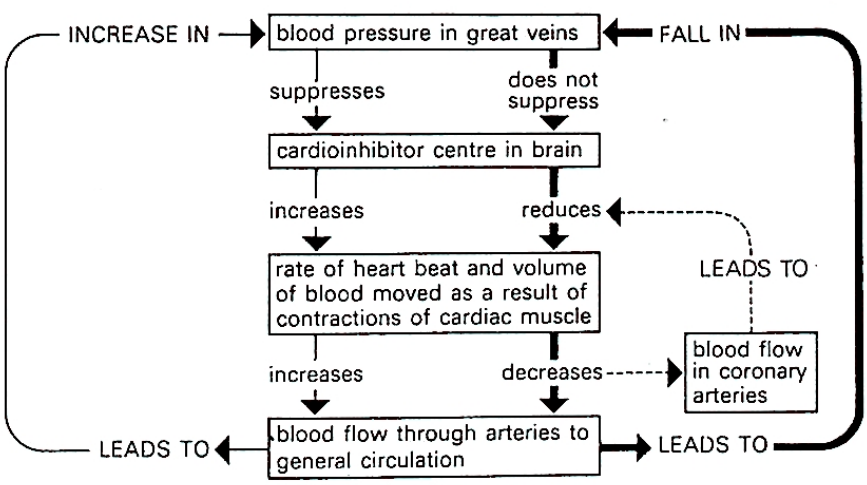
Speakers
Professor S. P. R. Rose
Professor G. N. A. Vesey
Dr P. Zorkoczy

The programme is a discussion between three members of the Staff of the Open University: Professor Steven Rose, Professor of Biology, who acts as Chairman; Professor Godfrey Vesey, Professor of Philosophy; Dr Peter Zorkoczy, Lecturer in the Faculty of Technology.

Professor Rose introduces the programme and asks Dr Zorkoczy to talk about the possible contributions of engineers to a better understanding of biological systems and their homeostatic properties. From this they proceed to compare the operation of computers with the functioning of the human brain. Professor Vesey then joins in a discussion of the implications of the development of extremely complex computers – how close can they come to the human state of being morally responsible for their decisions?

Before listening to the programme, you should read Sections 18.4, 18.4.2 and the remaining Pre-broadcast notes.

Dr Zorkoczy refers to the problem of heart function following massive loss of blood, e.g., as a result of a road accident. Look at Figure 28 of the Main Text to remind yourself of the systems involved in control of the heart beat under normal conditions, when the volume of blood in the circulation remains almost constant. Look at the system coloured grey and consider the results of the changes in the blood pressure in the great veins. The system is shown below, arranged in a different way. When the pressure rises in the great veins, the cardioinhibitor system is *suppressed* so the rate of heart beat and volume of blood moved *increases* (as shown on the *left* side of the following diagram). This means an *increase* in the arterial circulation and fast flow of blood round the body.



What happens when the blood pressure in the great veins falls? There is no suppression of the cardioinhibitor centre so the heart rate and amount of blood moved are reduced and there is a decrease in the arterial circulation. An additional effect is that the reduced blood supply to the coronary arteries leads directly to reduced heart output. These two effects are shown on the *right* side of the diagram (above).

How is the change in amount of circulating blood normally corrected? This depends on other systems–for instance, slower movement of blood through a normally active body means that more CO_2 becomes dissolved in it; this reaches the carotid arteries and stimulates the cardioaccelerator system to 'take over' from the inhibitor system (check this in Figure 28 of Unit 18). After a bad accident, however, the body is limp, probably unconscious, and this means that comparatively little CO_2 accumulates so that the accelerator centre is not stimulated. The heart remains under cardioinhibitor control and

the circulation continues to slow down leading to the 'runaway' situation described by Dr Zorkoczy. Thus a complex arrangement of balanced systems that control the heart efficiently under normal conditions can lead to disaster when there is a massive loss of blood.

Post-broadcast Notes

Summary of the programme

Dr Zorkoczy referred to heart function to show that principles developed by engineers could help to explain some biological observations. Pressed by Professor Rose to discuss the potentialities of computers, he concluded that the powers of computers depended on the intelligence and ingenuity of those who designed and programmed them. Professor Vesey considered that computers could not be treated as human, unless and until they could assume the sense of moral responsibility characteristic of human beings. Professor Rose concluded that modern computers, although some were programmed to control potentially dangerous situations, were still far from becoming rivals in intelligence to ourselves.

RADIO UNIT 19

Pre-broadcast Notes

Subject
Natural Selection and Human Evolution
Speaker
Professor J. S. Weiner

This programme consists of a talk given by Professor J. S. Weiner, Department of Environmental Physiology, The London School of Hygiene and Tropical Medicine. In it he describes what is known about the action of natural selection on the emergence of the genus *Homo*, and something of its effects on present-day man. Professor Weiner also examines Darwin's predictions of what human fossils would be found.

Figures 1, 2 and 3 will be referred to during the broadcast. You should also have Figure 19 (p. 55) from the main text in front of you during the broadcast.

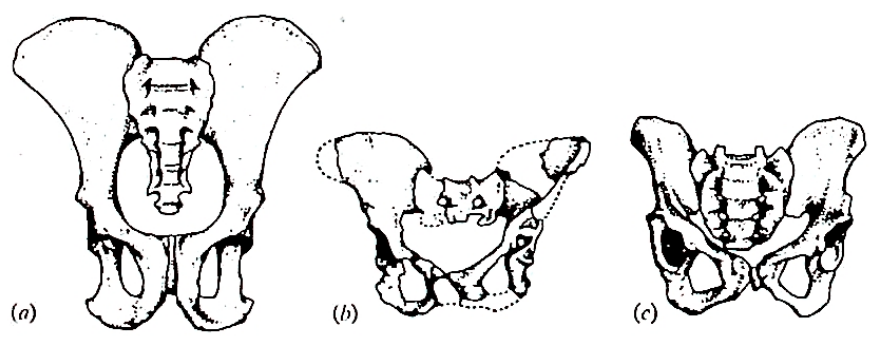


Figure 1 Pelvises of (a) *gorilla* (b) Australopithecus *and* (c) *modern man.*

Figure 2 Flint tools from the Middle Pleistocene, found in France, Kenya, South Africa and Swanscombe in Kent.

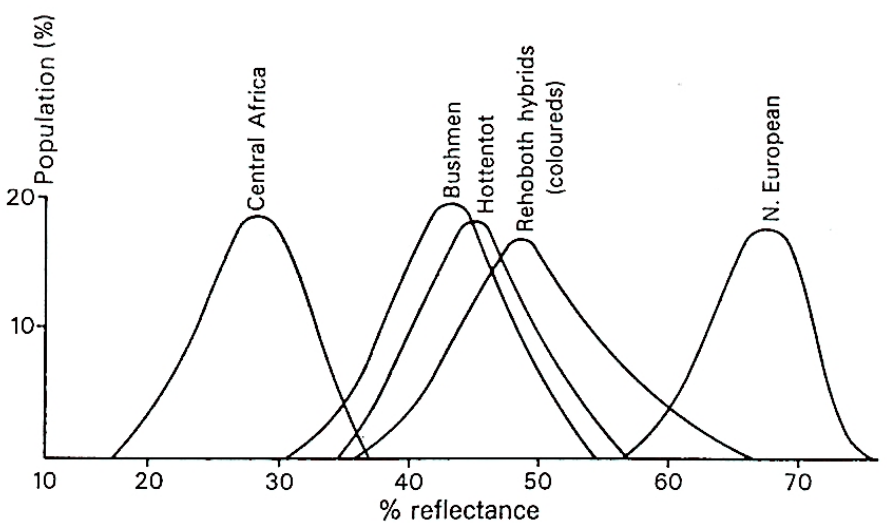


Figure 3 The percentage reflectance from the skin of various races of modern man.

RADIO UNIT 20

This will be a feedback programme. The notes associated with this programme will be sent to you in a separate mailing.

RADIO UNIT 21

Pre-broadcast Notes

Subject
The Implication of Evolution
Speaker
Professor A. J. Cain

You will find it helpful if you have, at least, skimmed through the text of the whole Unit before you listen. You should also read the summary of Unit 19 to remind yourself about the theory of natural selection and the evolution of man. Professor Cain of the Department of Zoology, University of Liverpool, is a zoologist who has investigated how to define species of birds (certain parrots); he has also observed natural selection in action by noting the predation by thrushes on populations of variously coloured varieties of snail.

Post-broadcast Notes

Biology, like other sciences is based on the observation of natural phenomena, and the collection of data, in this case about living organisms. It was generally believed, until the nineteenth century, that organisms had been designed by a Creator. Some of their parts showed obvious adaptation to their functions, but other parts appeared to be non-adaptive. Thus the plan of the five-fingered limb of vertebrates was there (according to the distinguished anatomist, Richard Owen, *Nature of Limbs*, 1849), 'so that its comprehension (could) lead rational and responsible beings to a better conception of their own origin and Creator'. Charles Darwin, however, was able to explain this plan in terms of evolution by natural selection – the apparently non-adaptive features are remnants of ancestral structures.

Further study of evolution has demonstrated that there is a tendency for living organisms to multiply and diversify up to the limits of the available radiant energy falling on the Earth; there is, however, no preferred direction. There is no evidence that evolution was specially intended to produce man or that the evolution of man was a different process from the evolution of other organisms. All living organisms are the result of natural selection acting upon variation, but at least this implies one reassuring conclusion: that man should be able to cope with the world as it has been modified as a result of his own activities.

You may find it interesting now to read in *The Roots of Present-Day Science* more about the impact of Darwinism on Victorian society, and on subsequent scientific ideas.

The talk is illustrated with shortened dramatized inserts from the writings of:

Henry More, *An Antidote against Atheism*, 1655.

William Paley, *Natural Theology*, 1803.

T. H. Huxley, *Collected Essays*, Volume VII: 'Man's Place in Nature', 1863.

George Bernard Shaw, *Back to Methuselah*, 1921.

RADIO UNIT 22

Pre-broadcast Notes

Subject
Seismology and Nuclear Explosions

Speakers
Professor I. G. Gass
Professor Sir Edward Bullard
Dr H. I. S. Thirlaway

Ever since the end of the Second World War, the prevention of nuclear war has been a major problem for humanity, as it has become increasingly apparent that nuclear war on a large scale could threaten the survival of the species. As a consequence of this there have been considerable political pressures directed towards abolishing nuclear weapons and, as interim measures, limiting their spread and prohibiting the testing of such weapons. To prohibit the testing of nuclear weapons, not only in outer space, in the atmosphere and under water, but also *underground*, requires that underground nuclear explosions be distinguishable from earthquakes. For many years, therefore, the prohibition of nuclear weapons tests was contingent upon the development of a particular scientific technique. In this programme, Professor I. G. Gass of the Open University discusses the political and general scientific aspects of the detection of underground nuclear explosions with Professor Sir Edward Bullard, Professor of Geodesy and Geophysics at the University of Cambridge, and Dr H. I. S. Thirlaway, Head of the United Kingdom Atomic Energy Authority's Seismic Unit. A more detailed scientific discussion of the problem is given by Dr D. Davies in *Understanding the Earth* (see Chapter 24, 'Nuclear Explosions and Earthquakes').

Post-broadcast Notes

The programme is summarized here by means of extracts from the various speakers.

Gass Professor Bullard, how was it that you . . . were involved in these early discussions relating to a possible nuclear test-ban treaty?

Bullard I was involved because I was a geophysicist and in any test agreement . . . one has to have arrangements for seeing that the agreement is being observed . . . one's got to consider carefully what happens when an explosion goes off in outer space or in the air, in the atmosphere or under the sea or underground and to consider all the phenomena that occur and whether these provide a means of detecting a violation of the agreement.

Gass What was the state of the game in 1958 so far as detecting nuclear explosions was concerned?

Bullard We know a good deal about the seismology of earthquakes, and really very little about the seismology of explosions . . . we gradually talked ourselves into a belief that if we put up about twenty stations . . . in Russia and corresponding numbers . . . in other parts of the world . . . we could detect explosions of about a few kilotons. . . . This looked good and resulted in a moratorium . . . not a treaty . . . simply a gentleman's agreement not to test.

Gass But what about the atomic tests in the early 1960s? Was there a breakdown in the moratorium?

Bullard Yes. . . . The talks in Geneva . . . became very acrimonious . . . in 1961 the Russians started testing again . . . the total explosions in 1962 amounted to 200 megatons . . . which raised the fallout to levels which were clearly becoming dangerous . . . stimulated the final agreement on a test ban which prohibited explosions in space, in the atmosphere and under water but still allowed them underground . . . in 1963 this agreement was reached.

Gass Dr Thirlaway, can you outline the developments in seismological detection over the last ten years?

Thirlaway Well let me take up the story from the conference of experts held in Geneva in 1958. At first there was general agreement, but later a difficulty arose following tests carried out by the Americans later that year. These showed that the ability to detect explosions was less satisfactory than had been hoped, so the problem was: could we make instruments sufficiently sensitive to detect seismic events and to distinguish clearly between natural earthquakes and man-made nuclear explosions?

We had to overcome the presence of the so-called microseisms caused by winds, waves on the sea-shore and so on, and we had to make the signals we recorded clearer. As we put it, we had to improve the signal-to-noise ratio. This last problem was in part solved by work done in the early sixties – the method was to set up a large array of about twenty seismometers, which would filter out the noise and leave the wanted signal. They were also to detect the direction of the first motion that comes in and they can be steered like a radio telescope electronically. But despite some success, the overall results weren't good enough. There were, however, other lines of attack opening up. You might think that the nearer you could get your instruments to the explosion, within limits, the better the results; but this isn't so. Like the Geneva experts, we at Aldermaston noticed that you got better, clearer recording if you were, say, three thousand to ten thousand kilometres away. The reason is that at this distance you're detecting waves that pass deep below the Earth's complex crust and so produce a cleaner signature of the original explosion or earthquake, whichever it might be. We had our first great success in 1962, when we recorded a clean, clear signal from an explosion nine thousand kilometres away. This changed our tactics, and from a large network of small arrays, we went over to the idea of some 25 large arrays spread over the world, preferably in the middle of continents where you can get away from the disturbances of waves on the sea-shore and other unwanted seismic noise.

We have these stations today in Scotland, India, Canada and Australia, and they are sited as far as is possible in homogeneous, geological areas, to get rid of the effects of faulting and other geological structures. At these sites the extraneous disturbances may be as little as a tenth of what you get elsewhere. The next advance was made in 1964, when we presented a theoretical basis for believing that explosions as well as earthquakes could be identified, provided seismic waves travelling along the surface of the Earth (surface

waves) could be detected as well as those which travelled through the body of the Earth (the body waves). Previously we could only identify those earthquakes which gave a first down-going motion at the receiving station or which generated very complex multiple body-waves. We were then left with a residue of rather simple looking events which began with an up-going motion of the ground, like an explosion, and which could either be explosions or earthquakes. We predicted that the amplitude of explosion surface waves would only be a tenth of those from earthquakes of similar size, and using apparatus that the Americans had developed, it wasn't long before we could distinguish explosion signals as such.

So we had achieved some measure of success, though it wasn't all as simple as it sounds; and provided the research and development is utilized in a specially built network, we have the possibility of recognizing explosions of not less than ten kilotons of TNT equivalent fired in hard rock. Below this level, it's not difficult to see that the energy of an explosion in soft rock like alluvium would be absorbed locally and so could be missed altogether. . . . If the advocates of a comprehensive test-ban treaty fail in their purpose, it certainly won't be for the lack of answers to technical questions.

Gass Can we identify all man-made atomic explosions any more clearly than we could, say, ten years ago?

Bullard Yes, undoubtedly we can . . . detection is, I would say, in a pretty good state . . . location is in a reasonable state . . . the nub of the matter is identification. . . . Was this an explosion or was it an earthquake? . . . One can do a certain amount without highbrow geophysics at all. The greater part of the Earth's surface hasn't got any earthquakes, or virtually no earthquakes: the earthquakes occur in seismic zones. The main area of old rocks in Russia is an almost completely aseismic area. . . . In particular, the Russian test site just outside Semipalatinsk is in an aseismic area–only just. It's a little surprising they didn't put it a few hundred kilometres further south to get into the seismic zone, but they didn't. And also the other test site, the one in Novaya Zemlya in the Arctic is also a pretty well aseismic zone, so that in point of fact there hasn't been any great trouble in identifying the things as explosions because all the things that occur in the test sites are explosions.

Gass What about the Americans? Have they been any more cunning?

Bullard If there's been an explosion there's no real problem; it's usually in the local newspapers.

Gass Is there a margin where you have to say we just don't know whether this was a naturally occurring earthquake or an explosion?

Bullard There will be earthquakes that someone will mistake for an explosion, and a treaty has got to contain some provision for investigating these. This is a purely political question about which there's been tremendous amount of negotiation and argument. . . . Also it is possible that there will be explosions which will be mistaken for earthquakes. Now here one has got to say, look chaps . . . this is an imperfect world, we are not going to get perfect safety. Nothing ever is ideal

and as you'd like it. If you are going to have a test ban you are going to have a test ban under circumstances where it is conceivable that you will be deceived. It might be that the enemy will succeed in making an explosion without your knowing about it. Well now, do you mind about it? Are you interested in detecting every last one on the assumption that there are any to detect, or are you willing to run the risk that someone will deceive you occasionally? Is it sufficient that he can't make a whole series of tests and get away with it? Well these are political questions and from my somewhat lengthy experience of politicians, my belief is that as long as they are fairly clear what they are doing they will accept risks of this sort.

Gass Is there a debit side to having a test-ban treaty?

Bullard There are two points there. One is that undoubtedly the many hundreds of millions of dollars that have been spent on this project—not only the crumbs from the rich man's table, but some pieces of bread and butter have fallen into seismologists' laps. . . . The other point is that if we have an underground test ban treaty we shall lose the possibility of using underground explosions for seismological reasons. And of course, we shall lose a lot more. We shall lose the peaceful uses of atomic explosions. The possibility of building a sea-level canal in parallel with Panama. The possibility of making a harbour in Alaska using nuclear explosions. . . .

RADIO UNIT 23

Pre-broadcast Notes

Subject
The Finite Earth

Speakers
Dr R. C. L. Wilson
Sir Kingsley Dunham
Dr T. F. Gaskell

This programme is about natural resources, in particular those to which the applied geologist devotes his attention, such as coal, oil and mineral ores. The subject matter of Units 22 and 23 owes much to the instrumentation necessary for the geophysical prospecting techniques evolved by applied Earth scientists. These techniques have helped produce a revolution in our understanding of the structure and evolution of this planet. Such knowledge, together with instruments capable of resolving relatively minor features within the Earth's crust, has so far enabled the discovery of new resources to keep pace with the consumption of those already known to exist. But how long will the Earth's resources last? This is the major question posed in the programme.

Post-broadcast Notes

Two contrasted views concerning the problems of obtaining material and fuel resources were presented during the programme. Dr Dunham* was pessimistic, pointing out that consumption of the Earth's resources had largely been confined to the last 100 years of civilization – and already shortages of some items were becoming acute. Dr Gaskell, though agreeing that fuel resources had at most a few centuries to run at their present consumption rate, considered that alternatives would be found, such as nuclear power, and plastics developed as substitutes for metals. The

**Now Sir Kingsley Dunham.*

contrasting view of the two speakers was comparable to the pessimistic and optimistic views put forward in Radio Unit 16 (the uses and abuses of biochemistry).

Both Dr Dunham and Dr Gaskell, despite their contrasting views, agreed that society must use the next one or two centuries to adjust itself to a situation in which resources were used only on a limited scale.

RADIO UNIT 24

Subject
Periodicities in the Earth's properties

Speaker
Dr W. A. Cooper

Pre-broadcast Notes

You must have these notes to look at during the programme. It would be useful to have pages 12 and 13 of Unit 23 in front of you as well.

Units 22 and 23 describe many different ways in which the Earth's mechanical properties, surface features and magnetic field change with time. Many of these changes repeat at fairly regular intervals. However, the lengths of these intervals differ enormously from one property to another – from a few seconds for fast changes in the magnetic field to tens of millions of years for continental drift. It is difficult to keep such vastly different times in perspective. The idea behind the programme is to show the pattern of all these different times, and in so doing to give a quick review of the material in the Units. The programme is built around Figs 1 and 2 (pp. 42 and 43).

There is only one thing you need do before the programme, and that is to learn how to use a logarithmic scale on a diagram. Both diagrams have logarithmic scales on both axes. Take the horizontal scale, which is the time scale. It is marked from -6 to $+18$. This means from 10^{-6} seconds to 10^{+18} seconds. The same convention applies to intermediate points, of course. For instance $+3$ means 10^3 seconds, that is 1 000 seconds (about 16 minutes). A year is just over 3×10^7 seconds (that is, 30 million seconds) and you will also see one year marked as an extra reference point. With such a wide range to cover, the only practicable solution is to use a logarithmic scale – the graph would have to be about a mile long if the scale were linear! The vertical scale uses the same system to display a wide range of values of length (Fig. 1) and magnetic field (Fig. 2).

If you need some practice, check the positions of one hour, one day and one year on the horizontal axis, and the position of one Earth radius (R_E=6 400 km) and 1 km on the vertical axis, of Figure 1.

Magnetic fields are given in SI units (weber per square meter=Wb m^{-2}) and also the old units (gauss, where 1 Wb m^{-2}=10 000 gauss). You don't need to be familiar with these units. It is only relative values which matter for this programme and the value of the Earth's total magnetic field (about 10^{-4} Wb m^{-2}, or 1 gauss) gives a reference point.

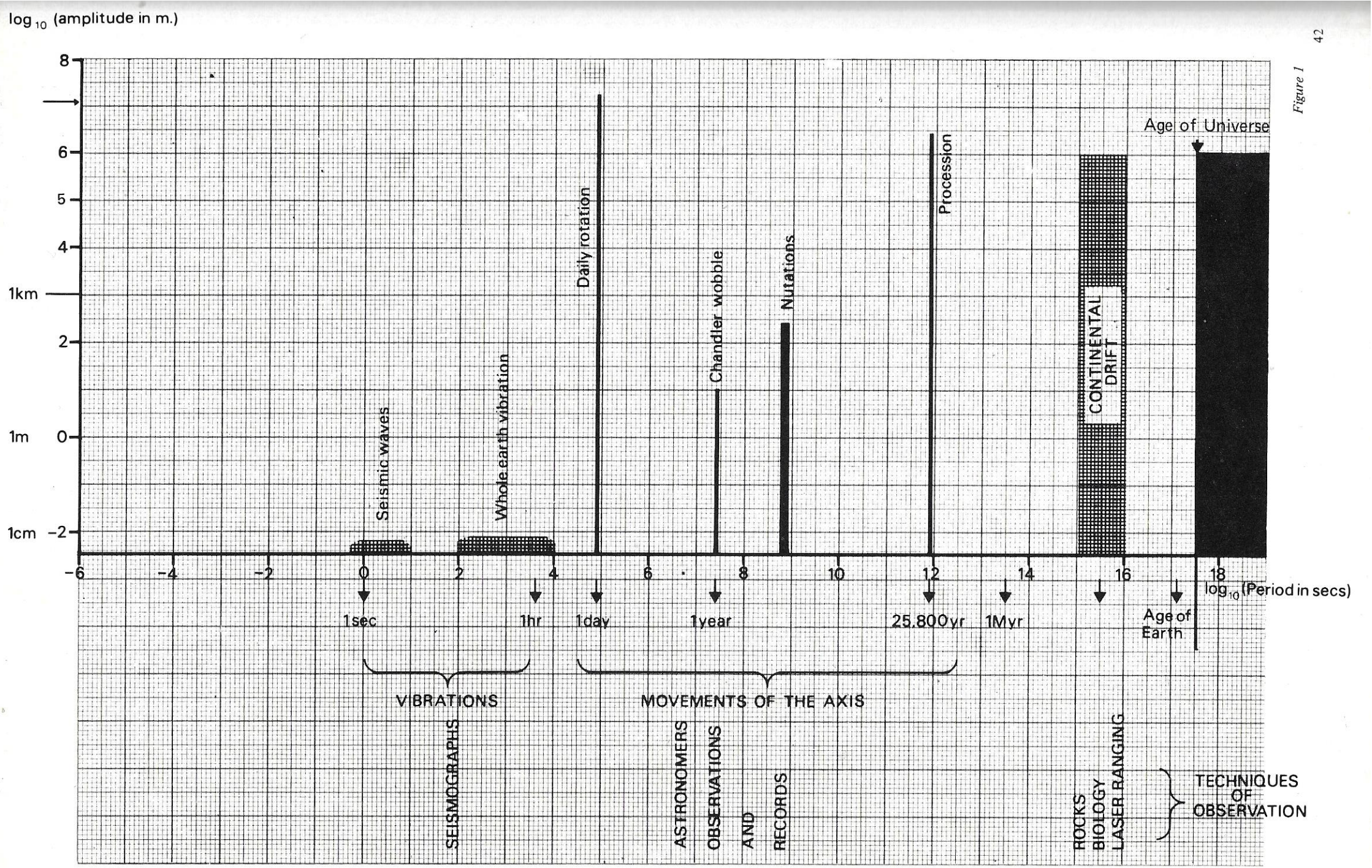

log 10 (amplitude in m.)
8
6
5
4
1km
2
1m
0
1cm
−2
Seismic waves
Whole earth vibration
Daily rotation
Chandler wobble
Nutations
Procession
CONTINENTAL DRIFT
Age of Universe
−6
−4
−2
0
2
4
6
8
10
12
14
16
18
log 10 (Period in secs)
1sec
1hr
1day
1year
25,800yr
1Myr
Age of Earth
VIBRATIONS
MOVEMENTS OF THE AXIS
SEISMOGRAPHS
ASTRONOMERS
OBSERVATIONS
AND
RECORDS
ROCKS
BIOLOGY
LASER RANGING
TECHNIQUES OF OBSERVATION

Figure 1

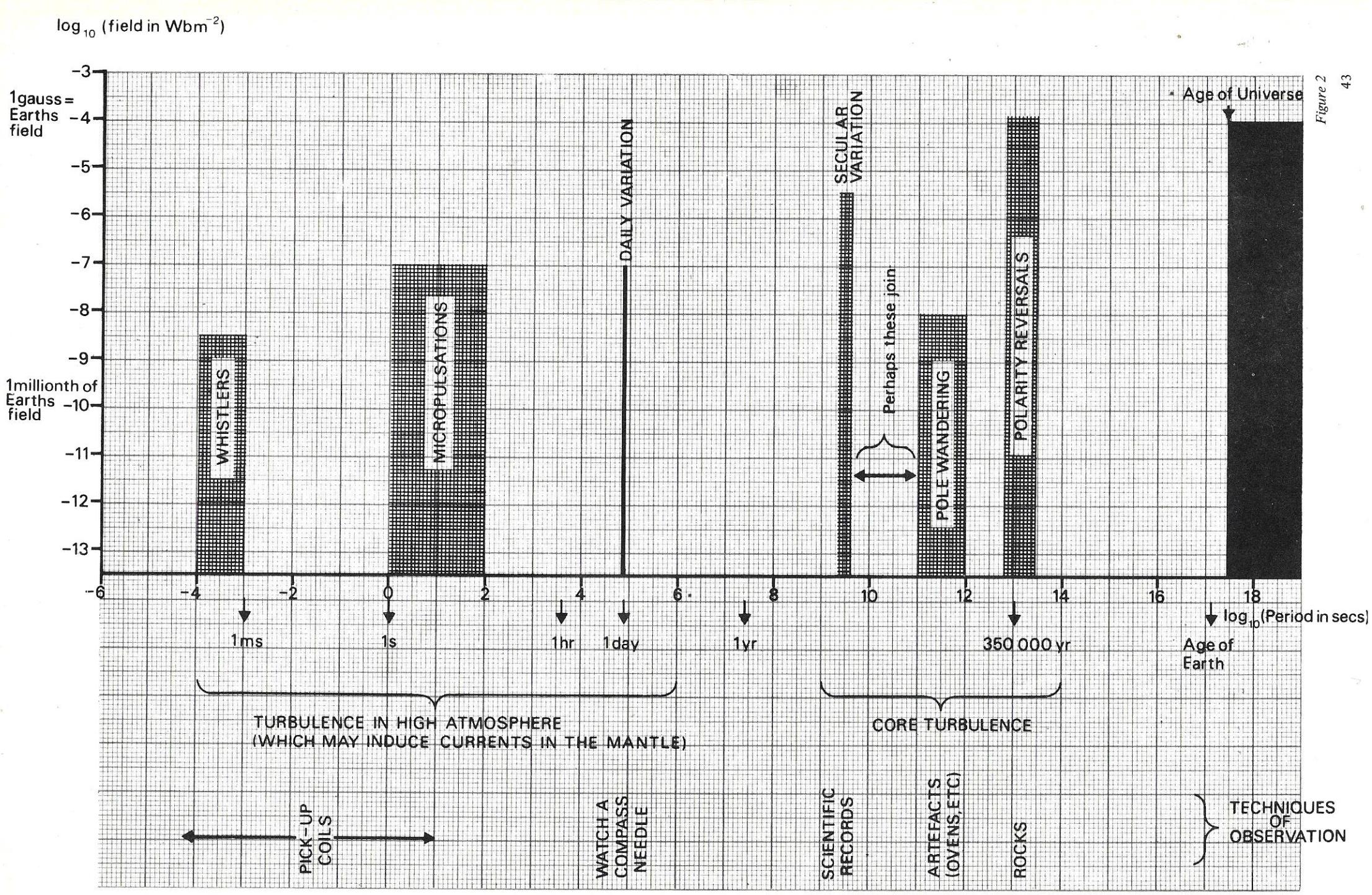

log10 (field in Wbm−2)
1gauss = Earths field
1millionth of Earths field
−3
−4
−5
−6
−7
−8
−9
−10
−11
−12
−13
WHISTLERS
MICROPULSATIONS
DAILY VARIATION
SECULAR VARIATION
Perhaps these join
POLE WANDERING
POLARITY REVERSALS
Age of Universe
−6
−4
−2
0
2
4
6
8
10
12
14
16
18
log10 (Period in secs)
1ms
1s
1hr
1day
1yr
350 000 yr
Age of Earth
TURBULENCE IN HIGH ATMOSPHERE
(WHICH MAY INDUCE CURRENTS IN THE MANTLE)
CORE TURBULENCE
PICK-UP COILS
WATCH A COMPASS NEEDLE
SCIENTIFIC RECORDS
ARTEFACTS (OVENS, ETC)
ROCKS
TECHNIQUES OF OBSERVATION

Figure 2

RADIO UNIT 25

Pre-broadcast Notes

Subject
Revolution in the Earth Sciences

Speakers
Dr Peter J. Smith
Professor J. Tuzo Wilson
Professor I. G. Gass

Dr Peter J. Smith, of the Open University, introduces Professor J. Tuzo Wilson of the University of Toronto and Professor I. G. Gass of the Open University who discuss the significance of the conceptual revolution which has recently taken place – and which is to some extent still taking place – within the Earth sciences. The programme is opened by Dr Smith who sets the scene as follows:

> From reading your set book *Understanding the Earth* and from studying the Earth science Units you've had so far, you may have got the impression that the most important discoveries in the Earth sciences have taken place within the past twenty years or so. And in a sense you'd be right. The picture of the Earth we have now is one of movement on a global scale. Palaeomagnetism, among other things, has shown us that for the past 200 million years the continents have been drifting along the Earth's surface. The study of the linear magnetic anomalies over the oceans has proved to most people's satisfaction that the ocean floors are spreading . . . in other words, material from the mantle upwells along mid-oceanic ridges, moves away sideways and finally plunges back into the mantle along the trenches. And according to the theory of plate tectonics, the Earth's surface layer may be regarded as a system of comparatively few rigid plates along the edges of which most of the world's seismic activity takes place. Of course, we don't know for sure just what keeps all this movement going . . . but we suspect it's all due to convection currents in the mantle, or more particularly, in the asthenosphere.
>
> But a question may have occurred to you already. If all these fundamental discoveries have been made during the past couple of decades, whatever were geologists doing before that? After all, the nineteenth century has traditionally been regarded as the great age of geology. Men like William Smith and Sir Charles Lyell are usually thought of as the founders of modern geology, men who put geology on a rational footing. Were they wasting their time? And what was their view of the Earth anyway?
>
> I hope we'll be able to answer some of these questions in this programme. But before we do, let's try to settle on a framework, as it were, within which these questions make sense. The truth is that the past twenty years have seen a conceptual revolution in the Earth sciences. Throughout the nineteenth century, geology operated under a certain set of accepted assumptions and principles. But by the early 1900s something had begun to go wrong. Anomalies had begun to appear which the current concepts were incapable of resolving. Looking back, it's clear that the only way these problems could have been solved . . . and indeed were solved . . . was to scrap the old ideas about the structure of the Earth and begin anew. Hence the revolution.
>
> Now you may have recognized this picture. If you've read Thomas Kuhn's *Structure of Scientific Revolutions* . . . as I hope you have . . . you should see, in the view of the Earth sciences I've presented, Kuhn's analysis of the way science progresses. A long period of what Kuhn calls normal science . . . in which the subject moves forward within a framework accepted by all within the particular scientific group . . . finally enters a revolutionary situation when the original concepts become no longer tenable. As the result, a new framework emerges which defines a new period of normal science.
>
> One of the first people to recognize that we are, in fact, in a revolutionary period within the Earth sciences . . . and certainly the first person to see in this situation a resemblance to Kuhn's analysis . . . was Professor J. Tuzo Wilson of the University of Toronto. I have Professor Tuzo Wilson here with me in the studio. He would, I think, regard himself as a geophysicist with both a geological and physical background. We also have Professor Gass of the Open University who is a geologist.

(*Note* Occasional words in the above quotation may differ from those in the actual broadcast because of subsequent editing of the latter.)

Post-broadcast Notes

It is not possible to summarize here the detailed points made by the speakers in the programme. In general, however, they discussed some of the changes the so-called revolution has brought about, some of the problems faced by pre-revolution geologists, how the revolution has helped (and been helped by) the economic geologists, attitudes to those few Earth scientists who do not accept the new view of the Earth, how the revolution has affected and been affected by other sciences, and a little about the future of the Earth sciences.

RADIO UNIT 26

I. Pre-broadcast Notes

Subject: *The Moon and its surface*

Speakers:
Professor I. G. Gass
Professor G. M. Brown
Professor M. J. O'Hara

This broadcast is about the Moon and in particular its surface features and how they were formed. In Unit 26 we delved back into the history of the Earth and found that the application of the principle of uniformitarianism was remarkably successful – up to a point. But when it comes to the very early history of the Earth, we have problems. The oldest known rocks on Earth are about 3 600 Ma old. Yet, there is good evidence that the Earth was formed 4 600 Ma ago. What happened during the 1 000 million years between? It is natural in trying to find the answer that we turn to the other bodies in the Solar System. One of these bodies, the Earth's companion in space, is the Moon. In this programme we enquire into how the Moon got its spectacularly cratered-surface and what it can tell us about the Earth's early history.

In Unit 27, you will be asked to read part of the article by Professor Kopal on 'The Earth-Moon System' in *Understanding the Earth* (pp. 96–113). It would be advisable to 'skim' through this article now to familiarize yourself with such terms as craters, maria, lunar highlands and the general lunar surface features.

RADIO UNIT 27

Pre-broadcast Notes

Subject:
Is life on the Earth unique?

Speakers:
Professor George Porter, F.R.S.
Professor Peter Sylvester-Bradley
Professor Jack Meadows

The programme takes the form of a discussion between a chemist (Professor George Porter of the Royal Institution), a geologist (Professor Peter Sylvester-Bradley of the University of Leicester) and an astronomer (Professor Jack Meadows of the University of Leicester). Professor Porter introduces the programme.

Before listening to the programme, you should have completed sections 2 and 3 of Unit 27. Most of the terms used in the programme are defined in earlier Units on biochemistry and in this Unit. If you have not read Unit 27, have the glossary open in front of you whilst listening to the programme.

In the TV programme of Unit 21, the Miller experiment was shown, in which organic compounds considered to be necessary precursors to the origin of life were synthesized by subjecting a mixture of methane, ammonia and water to an electric discharge. These experimental conditions are considered by some to simulate the environment which existed immediately prior to the origin of life. The discussion in this programme concerns the nature of the energy which synthesized organic compounds and of the Earth's primitive atmosphere. Was the energy derived from the sun, or from within the Earth? Was the Earth's primitive atmosphere similar to that used in the Miller experiment (a *reducing* atmosphere) or composed of nitrogen and carbon dioxide (a *non-oxidizing* atmosphere)?

Post-broadcast Notes

The discussion in the programme ranged over most of the subject-matter covered in section 2 of this Unit. You should have noted how each authority was influenced by his subject speciality.

RADIO UNIT 28

This will be a feedback programme. The notes associated with this programme will be sent to you in a separate mailing.

RADIO UNIT 29

Pre-broadcast Notes

Subject
The Beginnings of Quantum Theory
Speaker
Professor F. R. Stannard

You may be having some difficulty in this Unit in understanding and accepting the ideas of quantum theory. If so, we hope you will take heart from this broadcast. In this talk, you will learn that even those eminent physicists who were collectively responsible for formulating the theory found it hard to cast off the old ways of thinking.

Post-broadcast Notes

None.

RADIO UNIT 30

Pre-broadcast Notes

Subject
Electrons in Single Atoms and in Solids
Speaker
Dr H. M. Rosenberg

The object of this programme is to show how the ideas of quantum mechanics as developed in this Unit can be extended to deal with the large numbers of atoms found in solids. This leads to an explanation of the basic properties of conductors, semi-conductors and insulators. Particular emphasis is placed on semi-conductors.

Figures 1–6 are on p. 47.

Throughout the programme Dr Rosenberg will refer to Figures 1 to 6. However, you should not attempt to read the main captions during the broadcast. They are included to serve as reminders of the key points and should be used as 'post-broadcast notes'. Dr Rosenberg will also refer to *Figure 14* of *Unit 30*, which you should have to hand.

Post-broadcast Notes

Whether material is an insulator, a semi-conductor, or a conductor, depends on the form of the electron bands and on how these are filled. In an insulator (Fig. 4) the bands are completely filled. In a conductor the band is partially filled (Fig. 3) and the electrons can accept energy from an electric field. In a semi-conductor the permitted energy bands are separated by a small gap and electrons may be either thermally excited across the gap (Fig. 5) or, as in Figure 6, an impurity level may be introduced which donates electrons to the band above.

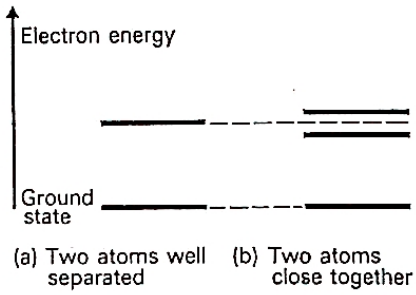


Figure 1 (a) The energy levels of two atoms which are well separated are the same.

(b) If the two atoms are brought close together their energy levels shift slightly relative to one another. The split is more pronounced the higher the energy level; the split in the ground-state level is negligible.

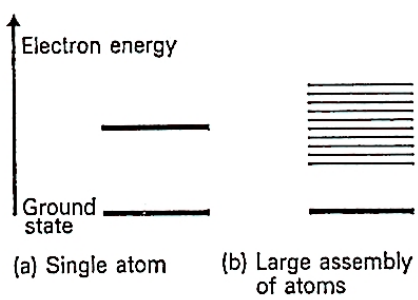


Figure 2 In a large assembly of atoms the energy levels of the single atoms (a) combine to form a band of energy levels (b) which are slightly separated from one another. In any real system the split energy levels in (b) would be much more finely split than indicated there.

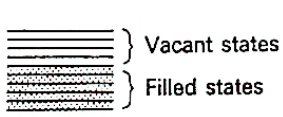


Figure 3 An energy band for a metal contains vacant states. The electrons can change their energy and so a current can flow.

Figure 4 An energy band for an insulator has all states completely filled. No current can flow.

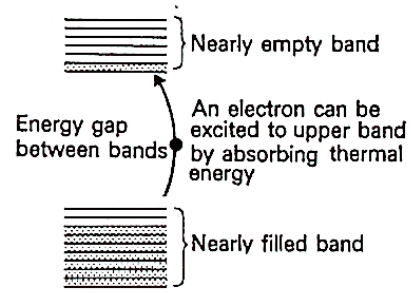

Nearly empty band
Energy gap between bands
An electron can be excited to upper band by absorbing thermal energy
Nearly filled band

Figure 5 The two-band scheme for a pure semi-conductor.

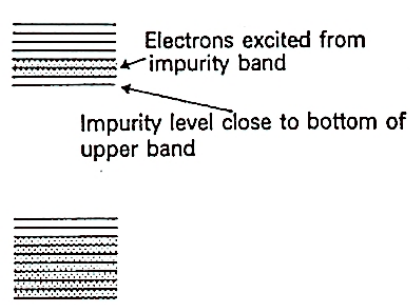


Figure 6 The band scheme for a doped semi-conductor showing a sharp impurity level close to the upper band. (The position of this level depends on the particular impurity that is used for doping.) Apart from the impurity level indicated in red (a so-called donor *level) there can also be levels introduced close to the tip of the lower band which can accept electrons from the lower band (these are called* acceptor *levels).*

RADIO UNIT 31

Pre-broadcast Notes

As you have learnt in the Main Text of Unit 31, binding energies of nucleons in atomic nuclei are many orders of magnitude greater than binding energies of electrons in atoms. Put in other words, the nuclear force that binds protons and neutrons together in the nucleus is many times stronger than the electromagnetic force that binds electrons to the atomic nucleus.

It is this fundamental difference—between nuclear and electromagnetic forces—that explains the extraordinary explosive power of nuclear weapons. Thus a nuclear weapon in which the explosive charge weighs only a few kilogrammes has an explosive power equivalent to that of kilotons or even megatons of TNT.

The realization, in the late 1930s, that such enormous energy could be released from the fission of uranium in an explosive device, confronted scientists and, indeed mankind, with an unprecedented moral and political problem.

The purpose of this radio programme is to give you some idea of how the scientists actually involved in the atomic bomb project—the so-called 'Manhattan Project'—reacted to the new and deeply disturbing social implications of nuclear energy.

Subject
The Building of the A-bomb

Speakers
E. H. S. Burhop, Professor of Physics, University College, London

Joseph Rotblat, Professor of Physics, St Bartholomew's Hospital Medical College

Otto Frisch, Jacksonian Professor, Trinity College, Cambridge

Samuel Goudsmit, Physicist who had the job of following the Allied Invasion Germany to discover how far German Scientific research on the A-bomb had gone

Werner Heisenberg, Distinguished German physicist who remained in Germany during the war

James Tuck, Former Oxford Physicist worked at Los Alamos

J. Robert Oppenheimer, Former Scientific Director of Los Alamos

Edward Teller, Worked at Los Alamos 'father' of the Hydrogen Bomb

Post-broadcast Notes

Summary

Chadwick's discovery of the neutron and the first artificial disintegration of the nucleus by Cockcroft and Walton in the early 1930s marked the beginning of a period of great excitement in nuclear physics. Nevertheless, Rutherford, in whose laboratories in Cambridge these discoveries had been made, was, in 1935, extremely sceptical about the possibilities of harnessing nuclear energy. The problems of social responsibility were still very remote from nuclear physics. Hahn and Strassman's discovery, in 1938, of the fission of uranium changed the situation overnight. The excess neutrons produced in this process made a chain reaction possible.

A year later, Nazi Germany invaded Poland and the Second World War began.

So great was the revulsion at Nazi doctrines that scarcely any nuclear physicist questioned working on the A-bomb project; indeed many of them, like Albert Einstein, Otto Frisch and Joseph Rotblat, were refugees from Nazi Germany. The only consideration was that the Nazis might develop the bomb and that it was essential that they should not have it first. Scientists in Britain and the USA imposed a voluntary censorship of all publications about nuclear physics.

Most physicists did, however, have some idea of how terribly destructive an A-bomb would be. As early as 1941, Enrico Fermi suggested to Samuel Goudsmit that one such bomb would flatten a large area of New York.

The German physicists who remained in Germany seemed to forget all ethical considerations and worked like good civil servants for their government. It is important to remember that the Allied physicists had not been faced with the question of what they would if do their governments had held a Nazi ideology. After the war some German physicists suggested that they had tried to obstruct the successful development of the bomb in Germany. However, Samuel Goudsmit, who, after the Allied invasion, had the job of finding out how advanced the German A-bomb project was, felt that this was a rationalization after the event and that for these scientists it was mainly a grandiose physics problem. This attitude was not absent in Los Alamos, the Californian site where the A-bomb was developed. James Tuck, who was a junior scientist there, remembers the excitement of working on such a challenging project amongst such distinguished physicists, and there was also the possible peaceful application of the work after the War.

Many of the scientists did feel that having worked on the bomb they would have some say in how it was used. In June 1945, a report by James Franck and signed by 64 scientists strongly advised that the bomb should be dropped first on a desert island as a demonstration. This advice was rejected. A scientific advisory committee of three Nobel Prizewinners and Dr Robert Oppenheimer, the scientific director of Los Alamos, did not think a demonstration would be effective and advised President Truman accordingly. But one should remember that this was before the bomb had been tested and its awful destructiveness realized.

After the dropping of the A-bomb on Hiroshima and Nagasaki feelings were mixed, but not so aghast as we might think today. Minds had become blunted by the enormous loss of life in Europe—fewer people were killed in Hiroshima than in the fire-bombing raids on Dresden and Tokyo. Most felt that a saving of life had been achieved compared with the lives that might have been lost in an invasion. Nevertheless, most felt that a demonstration should first have been carried out, but, as Oppenheimer puts it 'There were passionate arguments—they did not persuade me one way or the other at the time—the alternative of the campaign of invasion was certainly much more terrible. . . . I think that Hiroshima was far more costly in life and suffering and more inhumane than it needed to have been to have been an effective argument for ending the war. This is easy to say after the fact.'

The story of the atomic scientists is told in this programme by Professor E. H. S. Burhop, F.R.S., who, as a young man, was one of those who worked on the bomb at Los Alamos. As Professor Burhop says, at the end of the programme, the moral problems posed, both for scientists and for society, by this example of the deliberate application of science on a large scale for destructive purposes are no longer unique. Nuclear disarmament has not yet been achieved. 'Conventional' wars, between small nations, and between large and small nations, continue. Science is being used on a large scale in Vietnam to defoliate forests, destroy crops—and produce incalculable ecological damage. The problem of responsibility in and for science is even sharper today than it was in 1945.

It is this problem that we shall be considering in greater depth in Units 33–34 of the Course.

RADIO UNIT 32

Pre-broadcast Notes

This programme is devoted to the discovery of the omega minus particle. You will hear Professors Gell-Mann and Ne'eman discussing how they came to propose the theory that led to the prediction of the particle. Professor N. Samios describes the excitement he and his fellow experimentalists experienced when their search for the omega minus eventually proved successful. Finally, Professor R. Feynman, another of the world's leading high energy physicists, speaks on the significance of the discovery. Before listening to the broadcast you should read Section 5 of the Main Text.

Subject
The Omega Minus Particle
Speakers
Professor M. Gell-Mann
Professor Y. Ne'eman
Professor N. Samios
Professor R. Feynman
Professor F. R. Stannard

Post-broadcast Notes

Professor Gell-Mann at one point referred to 'The Eight-fold Way'; that was his original name for the theory.

You might be interested in seeing the bubble chamber photograph of the first Ω^- particle – the one obtained by Professor Samios and his collaborators. It is reproduced as Figure 1. At first sight, a very ordinary-looking photograph! You may well wonder what all the fuss was about. Which is the Ω^-?

Figure 1 is on p. 51.

To answer that, we invite you to join us in a piece of detective work; we shall approach the analysis of the photograph in much the same way as a bubble chamber physicist might. Starting from the visible tracks caused by the charged particles we progressively add in the unseen flight paths of the neutral particles, and so gradually build up the complete picture of what is going on. For this purpose we shall have to rely on a computer – so let us imagine we have one.*

Where shall we start? It does not really matter, so let us begin with the electron pairs.

Can you see any on this photograph?

There are two electron pairs. These are drawn in Figure 2 to help you locate them on the photograph.

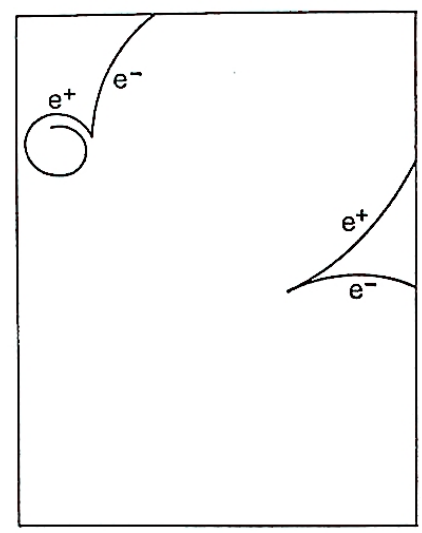


Figure 2 A drawing to show the positions of two electron pairs on the photograph of Figure 1.

How are electron pairs produced?

Electron pairs are produced by γ-rays (high energy photons). The γ-rays cannot be seen in the photograph because they carry no electric charge. However, the directions of the γ-rays can be deduced rather accurately by extrapolation of the initial directions of the two electrons of each pair. When this is done by the computer, it is found that neither γ-ray has a visible origin from which it could have come. Instead the two flight paths intersect each other at a point in space (Fig. 3). Something must have happened at this point to produce the γ-rays.

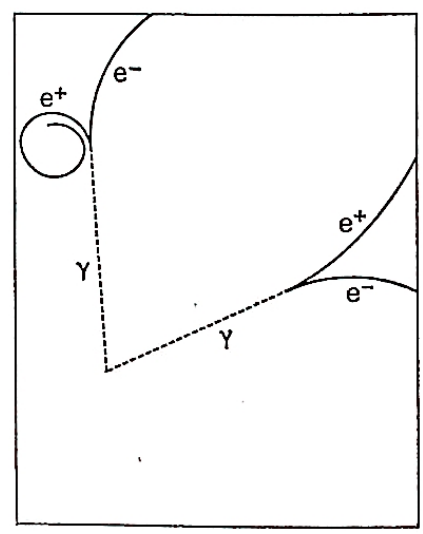


Figure 3 The γ-rays producing the electron pairs intersect at a point in space.

*This is just an invitation. If you prefer, you may skip the rest of these Broadcast Notes and refer directly to the final diagram – Figure 7. It is quicker that way – but perhaps not so useful.

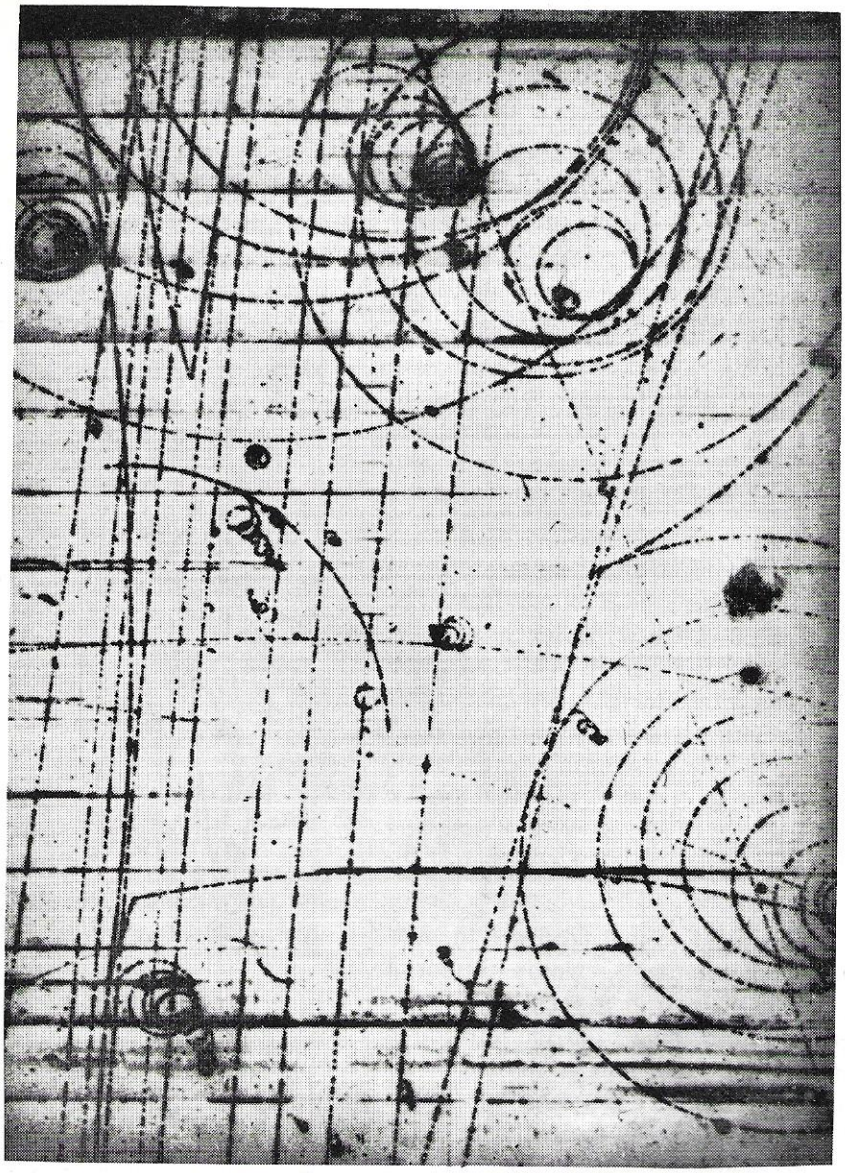


Figure 1 The bubble chamber photograph on which the omega-minus particle was discovered.

Can you remember a particle that decays into two γ-rays?

A π° meson is known to decay into two γ-rays. Could a π° have decayed at the point of intersection of the paths of the two γ-rays? The momenta of the γ-rays are known because they are equal to the combined momenta of the two electrons in each pair, and these may be estimated from the magnetic curvature of the electrons. The computer takes the momenta of the two γ-rays and their directions and applies the principles of energy and momentum conservation to their production. It is found that the decay of a π° is perfectly in accord with these observations. In coming to this conclusion the computer had to calculate the momentum and direction of the π°—this information will be used again later.

What can be said about where the π° was produced?

You may remember that the π° travels hardly any distance before it decays. The point where the two γ-ray flight paths intersect can therefore be taken to be the point where the π° was produced.

We turn next to the V-shaped event in the photograph, represented by the drawing in Figure 4.

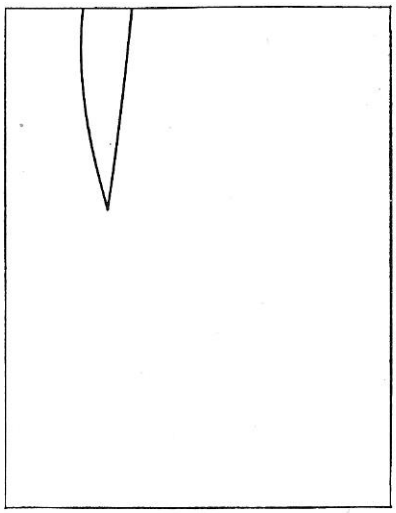


Figure 4 A 'V-shaped' pair of tracks on the photograph of Figure 1.

Can you guess what kind of interaction this might represent?

It represents the decay of a neutral particle into a positive and a negative particle. Once again the computer steps in. It takes the momenta of the two tracks, as deduced from magnetic curvature, and applies the principles of momentum and energy conservation to the decay process. It is found that the interaction is consistent with the decay of a Λ° particle into a proton and π^-. The computer moreover calculates the momentum and flight path of the unseen Λ°. It is found that *the flight path of the Λ° passes through the point where the π° was produced!*

It therefore appears that the Λ° and π° were produced at the same point in space. Could they in their turn have come from the decay of something? The answer is once again—yes. This time the computer takes the known directions and momenta of the Λ° and π°, and from them constructs the decay of a Ξ° particle (Fig. 5).

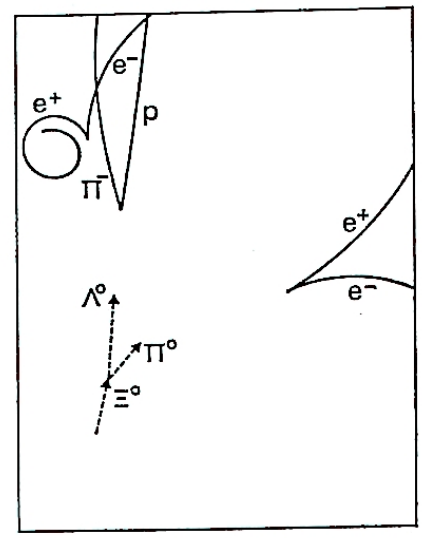


Figure 5 The Λ^0 and π^0 are found to come from the decay of a Ξ^0.

The point at which the Ξ° decays is known, and so are its momentum and direction. We may now ask the computer where the Ξ° comes from! The answer is given in Figure 6; the flight path of the Ξ° passes through the decay point of another particle. This particle is produced in an interaction involving an incoming beam particle, and it then travels a few centimetres in the chamber before decaying into the Ξ° and a negatively charged track. The magnetic curvature and the number of bubbles per unit length along this negative track give it the appearance of a π^- meson. But what kind of particle decays into a Ξ° and π^-? The mass deduced by the computer corresponds to no known particle–but it is close to that expected of the Ω^-!

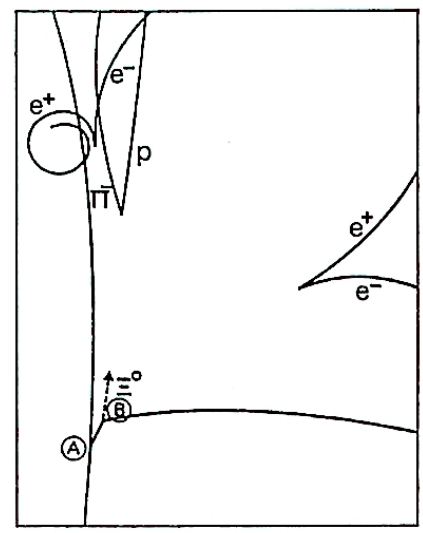


Figure 6 The Ξ^0 is found to come from the point B, the decay of a particle that is produced in a collision at A.

The case is clinched by a study of the interaction that produced the new particle. The interaction was caused by the incoming K^- meson (this much is known from the manner in which the particles from the accelerator were separated). The positively charged particle coming from the interaction can be identified by its curvature and the number of bubbles per unit length, as a K^+ meson. The computer indicates that energy and momentum can be conserved if in addition there is an unseen K° meson going to the left. Thus the interaction may be represented by:

$$K^- + p \rightarrow \Omega^- + K^+ + K^\circ.$$

Using the strangeness assignments listed in Table 1 of *SAQ* 13 check the strangeness value of the Ω^-.

The strangeness of the initial $(K^- + p)$ state is $(-1+0) = -1$. The strangeness of the final $(\Omega^- + K^+ + K^\circ)$ state is $(s+1+1) = (s+2)$, where s is the strangeness of the Ω^-.

$\therefore -1 = s+2$

$\therefore s = -3$

In Figure 7 you can see a drawing setting out the complete interpretation of the photograph.

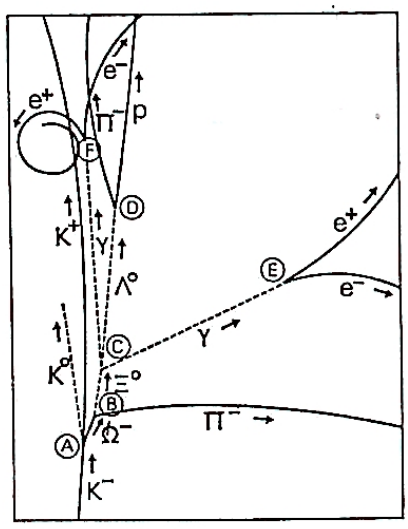


Figure 7 The complete interpretation of the photograph of Figure 1. (The unseen flight paths of neutral particles are shown with dashes.)

At A: $K^- + p \rightarrow \Omega^- + K^+ + K^0$

At B: $\Omega^- \rightarrow \Xi^0 + \pi^-$

At C: $\Xi^0 \rightarrow \Lambda^0 + \pi^0$ *followed by* $\pi^0 \rightarrow \gamma + \gamma$

At D: $\Lambda^0 \rightarrow p + \pi^-$

At E and F: $\gamma \rightarrow e^+ + e^-$

RADIO UNIT 33

Subject
Science and Society I: Implications of the proposed increasing reliance on nuclear energy

Speakers
Dr Frank Barnaby,
Dr E. F. Schumacher, Economic Adviser to the National Coal Board.
Mr G. C. Dale, Deputy Chief Nuclear Health and Safety Officer (Safeguards), Central Electricity Generating Board.
Dr David Butt, Reader in Physics, Birkbeck College, University of London.

Pre-broadcast Notes

We advise you to read Section 34.2.2 of the combined Units 33 and 34 before you listen to this radio programme. This section deals with nuclear energy and, in particular, the perspectives and problems of the large-scale application of nuclear energy to the generation of electricity.

The radio programme consists of a discussion between those who welcome a rapid advance into a substantial reliance on nuclear energy and those who are not so cheerful about the prospect.

Post-broadcast Notes

Summary of the programme

Dr Frank Barnaby starts the discussion by expressing the view that we shall inevitably go over to increased dependence on nuclear energy as a source of electrical power. He maintains that electricity produced by this means is likely to be cheaper than that produced from any other source, and that it will become increasingly cheaper, whereas electricity produced from conventional fuels is unlikely to become cheaper.

Mr Dale then describes how Britain has relied on nuclear energy for electricity generation to a far greater extent than any other country has done. He mentions the number of 'Magnox' type reactors* that are in operation and the experiments with 'advanced gas-cooled reactors' (AGR). The development of the fast 'breeder reactors' at Dounreay is of special importance, as such a reactor can provide a means of 'breeding' more fissile plutonium 239 (from ordinary uranium 238) than it consumes. The successful development of large breeder reactors will mean that reserves of nuclear 'fuel' would be virtually limitless.

Mr Dale's tone of easy optimism and evident satisfaction with the achievements of the CEGB in nuclear energy provokes Dr Schumacher into a direct contradiction: he says that the CEGB's nuclear energy story is not a success story at all – it is a big failure. Electricity produced from nuclear energy *at the present time* costs more than electricity produced from conventional fuels. Dr Schumacher claims that the Electricity Board has misled the public by failing to distinguish between facts and hopes for the future. Dr Schumacher goes on to say that he is not necessarily against nuclear power. We should always experiment with possible new power sources, but in this country we should have gone into it in an experimental manner, as most other countries have done, rather than embracing it immediately from the word go for political reasons or whatever, and without really knowing what dangers are involved, or even whether it is actually cheaper.

This leads the discussion on to the dangers arising from the problem of radioactive waste disposal.

Dr Butt maintains that Britain's record is generally pretty good, that the nuclear authorities producing radioactive waste stay well within the safety limits laid down by international agreements, and that the danger is not that we cannot contain it but that if accidents did occur then the danger to the public would be very great.

Dr Butt agrees with Dr Barnaby that there should be a system of international control of the movement of radioactive waste material.

** Magnox is an alloy of magnesium and beryllium used to can the uranium fuel elements in the reactors.*

Mr Dale describes the British practice of radioactive waste disposal – storing the high-activity waste in concentrated liquid form in containers underground, and releasing low-activity liquid wastes as effluents into the sea. He remarks that the danger of depositing these low-activity wastes in the sea is not serious, as the sea is radioactive already – but if, in the future, it were to be decided that one ought not to release even this small amount of radioactivity into the sea, then we could get around the problem, *at a price*, by solidifying liquid wastes. And similarly, one could suppress the release of gaseous wastes.

Mr Dale's optimism once more provokes Dr Schumacher to say that this is misleading – Mr Dale is talking about hopes rather than achieved facts. One may be confident that present methods of waste disposal are satisfactory – but would they still be if there is such a massive increase in our reliance on nuclear power? In Dr Schumacher's view, neither Mr Dale nor anybody else really knows whether we could get rid of these increased quantities. We are rushing too quickly into a massive development of nuclear power. We only hope we can cope with the problems, but we do not know we can. The trouble is that people are not even thinking about these problems, they are not even aware there is a problem. But in America, people like Gofman and Tamplin (see Main Text, Unit 34, p. 96) have alerted the public, who are very wary of the dangers, whereas in this country there is no discussion and people are too complacent.

Mr Dale replies that this kind of argument really amounts to putting a stop to technology – and if we did that, our standard of living would drop considerably; we would lose many advantages that people now take for granted.

As Dr Barnaby says in his concluding remarks – there is clearly a controversy here. There are risks involved in this new technology, but there are always risks with any new technology. What we have tried to do in this programme is to show how people illustrate their cases.

We have deliberately not come down on one side or the other. We have left it to the students to make up their own minds. What do you think?

RADIO UNIT 34

Pre-broadcast Notes

Subject
Science and Society II:
a feedback programme on TV 34

Speakers:
Professor M. J. Pentz
Professor Steven Rose
Dr Alan Durrant
Bob Cordell
and a group of S100 students

In other universities, controversial questions such as those dealt with in the TV programme of this Unit would be open for discussion in the lecture theatre, the seminar room, the common room – wherever students and staff could get together and talk to each other. This kind of opportunity is more difficult to provide in the Open University, with thousands of students scattered all over the country. But in this radio programme we have done the next best thing, by bringing a group of students from a particular locality into the local studio to discuss with members of the academic staff some of the questions raised in the TV programme.
You may feel that if *you* had been there, you would have made a different comment, drawn attention to a different angle. At any rate you would have done better than those silly so-and-sos . . . If our radio programme provokes you this much, it will have partly served its purpose. If it also provokes you to study these complex and important problems further it will have entirely served its purpose.

RADIO UNIT B

This will be a feedback programme and the notes will be sent to you in a separate mailing.